EGL99-032

The Environmental Impacts on the Great Lakes Region of North American Economic Integration

Final Report

March 2001

Submitted by:

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As stipulated under Grantee Reporting Requirements, this document will describe work accomplished during the activity period, the results of this work, problems experienced in performing the project, and deviations from previously agreed upon work. The main deviation was an extension of the project deadline from September 2000 to March 2001.

Initial Literature Review

Before commencing work on the tasks outlined in the final scope of work, I conducted a detailed literature review of both NAFTA and the environment and the environmental impacts of North American economic integration and the Great Lakes. To my surprise, I discovered *very few empirical studies* on either topic. I have found that the work conducted on this project has filled a niche and, consequently, I have had success in the dissemination of projects results at conferences and refereed journal articles.

Grossman and Krueger (1993) combined the output effects of NAFTA as simulated by Brown, Deardorff and Stern (1992) with data from the U.S. Environmental Protection Agency on toxic pollution. With regard to the direct impacts of trade liberalization (as opposed to liberalization-induces increases in investment), these authors found that the greatest increases in toxic pollution occur in the U.S. chemicals sector and the Canadian base metals and rubber and plastics products sectors. Other significant trade-induced increases in toxic pollution occurred in the Mexican electrical equipment sector, the U.S. paper products sector, and the Canadian transportation equipment sector.

Beghin, Roland-Holst, and van der Mensbrugghe (1995) employed a single-country, dynamic AGE model of Mexico. In one simulation scenario, these authors consider "a piecemeal unilateral trade liberalization, along with a modest increase in export prices to mimic terms-of-trade effects that would follow from NAFTA, and increased access to North American markets" (p. 781). The results suggest that trade liberalization contributes to increases in pollution levels, especially in the energy sector. Beghin, Roland-Holst, and van der Mensbrugghe show, however, that these negative pollution impacts can be offset by appropriate abatement policies.

A final empirical study by Abler and Pick (1993) focuses narrowly on the Mexican horticultural sector. Using econometric techniques, these authors conclude that NAFTA contributes to a slight increase in pollution in the Mexican horticultural sector but a slight decrease in pollution in the U.S. horticultural sector. Whether these results can be generalized to the agricultural sector as a whole is not clear.

On the specific subject of this project, the environmental impacts on the Great Lakes region of North American economic integration, I found *no empirical studies*.[1] The lack of empirical results confirmed that the proposed research is worthwhile. Given that the project has resulted in a number of published papers, I can safely claim to have made a contribution to better understand of the issues involved.

Linear Analysis of Economic-Environmental Linkages

Next, I utilized a 1991 social accounting matrix of North America and a set of industrial pollutant satellite accounts to conduct a *linear multiplier analysis* of industrial pollution linkages within the North American economy. The industrial pollutant satellite accounts were based on the World Bank's Industrial Pollution Projection System (IPPS). This analysis has been summarized in a paper entitled "Industrial Pollution Linkages in North America: A Linear Analysis." This paper is attached as Appendix A and has been accepted for publication in *Economic Systems Research* in 2001. This study takes us some distance in identifying where the largest pollution problems will arise as a result of the greater integration of the North American economies.

With regard to direct, inter-country linkages, the pollution linkages from Canada and Mexico to the United States differ. Both countries have significant direct linkages in the paper, chemical, base metals, and non-metalic mineral sectors.[2] Mexico, however, has very significant linkages in petroleum sector, which have been the subject of some discussion in the NAFTA and environment debate. Across pollutants, the sectors in which the largest direct linkages occur can differ between Canada and Mexico. For example, in the case of NO2, the largest pollution linkages from Canada and Mexico occur in the chemical and petroleum sectors, respectively. In the case of biological

[1] See, however, Allardice and Thorp (1995) for general environmental issues in the Great Lakes region.

oxygen demand, the largest pollution linkages from Canada and Mexico occur in the chemical and paper sectors, respectively. For a given pollutant, rankings can also change. For example, the largest particulates linkage from Canada is in the non-metalic mineral product sector, while the largest such linkage from Mexico is in the base metals sector.

Direct inter-country, industrial pollution linkages transmitted from the United States to Canada and Mexico are smaller, and this reflects the relatively low propensity of the United States to import from its two North American partners. These second category of linkages are very much concentrated in the petroleum and base metal sectors. Additionally, the paper sector plays a large role as a pollution linkage from the United States to Canada. For biological oxygen demand, the food processing and beverages sectors are important as a pollution linkage from the United States to Mexico.

A final important result is in the area of water pollution. *The base metals sector plays a significant role in transmitting total suspended solids pollution across borders in North America.* This would seem to constitute an area of concern for policymakers worried about contributions of North American economic integration to water pollution levels.[3]

Indirect inter-country, industrial pollution linkages are transmitted from Canada, the United States, and Mexico, respectively, through their two trading partners, and back onto themselves. For the United States and Mexico, base metals and petroleum are the sectors with the strongest, indirect pollution linkages. For Canada, the pattern is somewhat different, with petroleum playing a less important role. Chemicals and paper feature strongly in both Canada and the United States in generating indirect inter-country pollution linkages, but this is not the case for Mexico. For volatile organic compounds and toxins, the transportation equipment sector generates significant indirect pollution linkages in Canada and the United States, but again this is not the case for Mexico.

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[2] The different multiplier types are formally defined in Appendix A.

[3] See Allardice and Thorp (1995) for some important observations on the role of water resources in the Great Lakes region.

Applied General Equilibrium Analysis of Economic-Environmental Linkages

I next utilized the 1991 social accounting matrix of North America, a set of industrial pollutant satellite accounts (again the IPPS data), and an applied general equilibrium model of the North American economy to simulate the effects of NAFTA on industrial pollution. This analysis has been summarized in two papers. The first is entitled "The Industrial Pollution Impacts of NAFTA: Some Preliminary Results." This paper was presented to the North American Symposium on Understanding the Linkages between Trade and Environment in October 2000 in Washington DC. This conference was sponsored by the Commission for Environmental Cooperation and will be published by the CEC in English, Spanish, and French in 2001.[4] This paper is attached as Appendix B.

The second paper is entitled "NAFTA and Industrial Pollution: Some General Equilibrium Results." This paper is attached as Appendix C. It was presented at the Eastern Economic Association meetings at the end of March 2000 in Crystal City, Virginia. It has also been accepted by the *Journal of Economic Integration* for publication in 2001.

With regard to industrial *air pollution* caused by trade liberalization in North America, the results suggest that the industrial air pollution generated as a result of NAFTA will be concentrated in a few particular sectors. These are petroleum, base metals, and transportation equipment. For particulates, carbon monoxide, sulfur dioxide, and nitrogen dioxide, the greatest increases occur in the U.S. base metals sector and in the Mexican petroleum sector. In the case of volatile organic compounds, however, the transportation equipment sectors of Canada and the United States are large sources. In terms of total air pollution emissions, the greatest increases are of carbon monoxide and sulfur dioxide in the United States and sulfur dioxide in Mexico. Significant reductions in air pollution occur in the Canadian and Mexican paper sectors and in the Canadian chemicals sector.

In the case of industrial *bio-accumulative metals pollution*, the petroleum sector plays a less important role than base metals and transportation equipment. The largest emissions are to land, and these occur in the Canadian and U.S. base metals and transportation equipment sectors and in the Mexican base metals sector. In terms of total

[4] See http://www.cec.org/programs_projects/trade_environ_econ/pdfs/Reinert.pdf.

emissions, the United States leads both Canada and Mexico, primarily as a result of changes in its base metals sector. Again the Canadian chemicals sector registers improvement in emissions, although these are slight.

In the case of industrial *toxin pollution*, transmission to air is important along with transmission to land. This is especially the case for the transportation equipment sector in Canada. The base metals sector is also important for the transmission of toxins to land in this country. In the United States and Mexico, the chemical sector appears as significant sources of toxins. Importantly, this is *not* the case for Canada where this is a *reduction* of toxin emissions in the chemical sector. This reflects the comparative advantage of the U.S. and Mexican chemical sectors over their Canadian counterpart. The U.S. base metals and transportation equipment sectors and the Mexican petroleum sector are also significant sources of toxins, and in terms of total emissions, the U.S. leads with toxic emissions to land and air.

Finally, for *water pollution*, the base metals sector is again a crucial source of effluents. This is particularly the case for total suspended solids in all three countries. In the case of biological oxygen demand, there is actually an overall decrease in Canada due to the contraction of the paper products sector. The Mexican petroleum sector is a significant source of total suspended solids, but this is an order of magnitude less than in its base metals sector. By far, the greatest concern with regard to water pollution as a result of NAFTA trade liberalization is the increase in total suspended solids from the base metals sector of the United States.

State-Level Analysis

The state-level analysis was conducted using the 1991 social accounting matrix rather than the 1996 social accounting matrix constructed for the project. This change was made in consultation with Ms. Emily Bankard and Mr. Jim Bredin of the Office of the Great Lakes. They agreed that use of the 1991 database and simulations would be sufficient for completion of the state-level results.[5] The state-level results were completed in collaboration with G. Chris Rodrigo of the School of Public Policy at George Mason

[5] The simulations provided by the subcontractor using the 1996 database were not, in my judgment, policy relevant.

University. These results are presented in a paper entitled "North American Economic Integration and Industrial Pollution in the Great Lakes Region." It is attached as Appendix D. This paper will be presented at the Twenty-Third Annual Research Conference of the Association for Public Policy Analysis and Management in November 2001. It will also be submitted to the *Journal of Policy Analysis and Management* for publication. Based on my experience with the other papers that evolved out of this project, I believe that publication prospects are good.

Overall, the state-level results indicate that the research project was worthwhile. In short, the Great Lake states count for a substantial portion of the additional industrial pollution emissions generated by North American economic integration. It is clear that the proximity of industrial capacity near the Great Lakes ecosystem, and the effects of North American integration on this industrial capacity, is a cause for concern. What follows is a summary of the results.

With regard to the changes in industrial *air pollution* in the Great Lake states caused by trade liberalization in North America, in the case of particulates, the two most important contributors are the base metal and transportation equipment sectors. This is also the case for sulfur dioxide and volatile organic compounds. For carbon monoxide and nitrogen dioxide, the two most important contributors are the base metal and chemical sectors. The petroleum sector is also of note as a significant source of some air pollutants. In case of sulfur dioxide, the Great Lake states account for just short of one half of the additional U.S. emissions cause by North American economic integration.

With regard to the changes in industrial *bio-accumulative metals pollution* in the Great Lake states caused by trade liberalization in North America, for all three pollution types (metals to air, metals to water, and metals to land), the base metals sector is the most important source of emissions. For the case of metals to land, the chemicals, wood and metal products and transportation equipment sectors are also significant sources. For all three pollution types, the Great Lake states account for approximately one half of the additional U.S. emissions caused by North American economic integration.

With regard to the changes in industrial *toxin pollution* in the Great Lake states caused by trade liberalization in North America, except for the case of toxins to water, where the transportation equipment sector is not important, the chemicals, base metals, and transportation equipment sectors are the most significant sources of pollution accumulating to air, water, and land. For toxin pollution, the Great Lake states are less important in contributing to U.S. totals than for air and bio-accumulative metals.

With regard to the changes in industrial *water pollution* in the Great Lake states caused by trade liberalization in North America, once again, the base metals sector appears as a significant source of emissions. In the case of biological oxygen demand, the food processing sector is also a significant source of emissions, and in the case of total suspended solids, so does the chemicals sector. The case of total suspended solids is very notable here in that the Great Lake states contribute approximately 60 percent of the U.S. total. *This type of water pollution would appear to be of major concern to the Great Lakes ecosystem.*

Finally, as suggested in the final scope of work, Appendix D provides results equivalent to the ones just described for the state of Michigan. For comparison purposes, the tables of Michigan results contain Great Lake totals.

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Appendix A:

Industrial Pollution Linkages in North America: A Linear Analysis*

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March 2001

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*Senior authorship is not assigned. We are grateful to two anonymous referees for very helpful comments. Further, we would like to thank Hugh Arce, Gordon Blaney, Charles Bowman, Antonio Aguilar Bueno, Joseph Flynn, Joseph Francois, Luis Alberto Ibarra, Mark Planting, Erik Poole, Ronald Rioux, Clint Shiells, David Wheeler, and Colleen Williams for data. This research was made possible with funding from the Office of the Great Lakes through the Michigan Great Lakes Protection Fund. Contact: Kenneth A. Reinert, School of Public Policy, George Mason University, 4501 North Fairfax Drive, MS 3B1, Arlington, Virginia, 22201, USA, kreinert@gmu.edu.

Industrial Pollution Linkages in North America:

A Linear Analysis

Abstract. In recent years, a surge of interest in the linkages between trade and the environment has occurred in the contexts of both regional and multilateral trade agreements. In this paper, we utilize a three-country, social accounting matrix (SAM) of the North American economy and data from the World Bank's Industrial Pollution Projection System (IPPS) to conduct a linear multiplier analysis of industrial pollution linkages in North America. We provide estimates of both direct and indirect inter-country effects for a detailed set of industrial pollutants. The strongest linkages occur in the petroleum, chemicals, paper, base metals, and transportation equipment sectors.

Introduction

In recent years, a surge of interest in the linkages between trade and the environment has occurred in the contexts of both regional trade agreements such the North American Free Trade Area (NAFTA) and multilateral trade agreements such as the Uruguay Round. On the whole, however, the debate over trade and the environment has been more rhetorical than empirical. This is unfortunate because, as has been amply demonstrated (e.g. Runge, 1994, Beghin and Potier, 1997, and Beghin, Roland-Holst, and van der Mensbrugghe, 1997), *a priori* reasoning alone cannot predict whether trade liberalization will have an overall positive or negative impact on the environment. This fact has prompted Beghin, Roland-Holst, and van der Mensbrugghe (1997) to call for "detailed sectoral modeling and estimation" of the linkages between trade and the environment in specific policy contexts.

A few empirical studies do exist. The case of trade and transboundary pollution has been examined by Whalley (1991) and Perronni and Wigle (1994). Economy-wide models of domestic pollution have been developed by Grossman and Krueger (1993) for the case of North America, by Beghin, Roland-Holst, and van der Mensbrugghe (1995) for the case of Mexico, by Lee and Roland-Holst (1997a,b) in the case of Indonesia and Japan, and by Ferrantino and Linkins (1999) for the case of the Uruguay Round. Examination of these studies provides further testimony to the usefulness of detailed, empirical analysis.[1]

The present paper focuses on the industrial pollution linkages within North America using a three-country social accounting matrix (SAM) of the region and the World Bank's Industrial Pollution Projection System (IPPS) effluent data in the form of satellite accounts. The SAM and satellite accounts are utilized in a linear multiplier analysis to assess the contributions of economic activity in a sector of one country on industrial pollution in another via input-output, trade, and final demand linkages. Since our knowledge about industrial pollution linkages is so limited, this paper takes us a short, but important distance in establishing how changes in the industrial structure of North America during its integration process might transmit pollution linkages across national boundaries. For example, it allows us to have some notion about how the

[1] For an econometric approach in the problem of carbon dioxide emissions in the European Union, see Barker (1999). A linked, econometric input-output model for the case of Austria can be found in Kratena and Schleicher (1999).

expected increase in transportation equipment production in each country will impact effluents in partner countries.

Environmental Satellite Accounts

Policy analysis of the linkages between trade and the environment requires information on a large number of parameters reflecting the initial values of relevant variables. A standard form of collecting these initial values in a consistent manner is the social accounting matrix or SAM.[2] In an ideal world, the monetary values of environmental services would be imputed and included directly into SAMs. However, as noted by Barker (1992), this often proves to be impossible. Some non-produced assets are valued in monetary terms in the new System of National Accounts (SNA) and the System of Environmental and Economic Accounting (SEEA). However, for most residual flows, it is common to retain the environmental information in their physical units in the form of satellite accounts.[3]

The present paper adopts the satellite-account approach to analyze the structure of industrial pollution in North America. Specifically, we utilize the sectoral effluent data described in Hettige, Lucas and Wheeler (1992) and Lee and Roland-Holst (1997a,b). These have been compiled as part of the World Bank's Industrial Pollutant Projection System (IPPS). Importantly for our purposes here, the IPPS pollutants include major air and water pollutants, as well as toxins, which have been part of the debate over NAFTA

[2] See Pyatt and Round (1985), Reinert and Roland-Holst (1997), and Pyatt (1999).
[3] On the SNA, see United Nations (1993a,b). On the SEEA, see U.S. Department of Commerce (1994). For a proposal to link an environmental module onto the SNA, see De Haan and Keuning (1996). This module adds two new accounts to the standard SAM to record emissions and extractions of environmental agents/resources and changes in environmental assets.

and the environment.[4] The IPPS data are utilized at the 2- and 3-digit ISIC levels and compose satellite accounts to a 1991 SAM for North America. The latter is described in the appendix. The SAM and satellite accounts are utilized in a multiplier exercise described in the following section.

Multiplier Analysis

To examine the industrial pollution linkages within the North American economy, we undertake a static and linear multiplier analysis. This analysis draws on the linear traditions of Pyatt and Round (1979), Goodwin (1983), Round (1985), and Roland-Holst (1990). To begin, define a n x n multi-country SAM as the matrix **S**. The row sums of **S** compose a column vector of incomes we denote as **y**. Column normalization of **S** yields the matrix of expenditure shares we denote as **A**. The income-expenditure identity can be written as:

$$\mathbf{y} = \mathbf{A}\mathbf{y} \tag{1}$$

We next partition the SAM into m endogenous accounts and k exogenous accounts. Equation (1) can then be rewritten as:

$$\begin{bmatrix} y_m \\ y_k \end{bmatrix} = \begin{bmatrix} A_{mm} & A_{mk} \\ A_{km} & A_{kk} \end{bmatrix} \begin{bmatrix} y_m \\ y_k \end{bmatrix} \tag{2}$$

We can express endogenous incomes as:

$$\mathbf{y}_m = \mathbf{A}_{mm}\,\mathbf{y}_m + \mathbf{A}_{mk}\,\mathbf{y}_k$$

or:

$$\mathbf{y}_m = \mathbf{A}_{mm}\,\mathbf{y}_m + \mathbf{x} \tag{3}$$

where **x** is a m x 1 column vector of exogenous injections.

[4] See Commission for Environmental Cooperation (1996) and the references therein.

Let us partition $\mathbf{A}_{mm}$ by country, where the subscripts 1, 2, and 3 denote Canada, the United States, and Mexico, respectively. Then we additively decompose the partitioned $\mathbf{A}_{mm}$ matrix as follows:[5]

$$A_{mm} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix} + \begin{bmatrix} 0 & A_{12} & A_{13} \\ A_{21} & 0 & A_{23} \\ A_{31} & A_{32} & 0 \end{bmatrix}$$

$$\mathbf{A}_{mm} = \mathbf{B} + \mathbf{C} \tag{4}$$

Substituting (4) into (3), we have:

$$\mathbf{y}_m = \mathbf{B}\mathbf{y}_m + \mathbf{C}\mathbf{y}_m + \mathbf{x} \tag{5}$$

And we can put this into a reduced form as follows:

$$\mathbf{y}_m = (\mathbf{I}\text{-}\mathbf{B})^{-1}\mathbf{C}\mathbf{y}_m + (\mathbf{I}\text{-}\mathbf{B})^{-1}\mathbf{x}$$

$$\mathbf{y}_m = [\mathbf{I} - (\mathbf{I}\text{-}\mathbf{B})^{-1}\mathbf{C}]^{-1} (\mathbf{I}\text{-}\mathbf{B})^{-1}\mathbf{x}$$

$$\mathbf{y}_m = (\mathbf{I}\text{-}\mathbf{D})^{-1} (\mathbf{I}\text{-}\mathbf{B})^{-1}\mathbf{x} \tag{6}$$

where $\mathbf{D} = (\mathbf{I}\text{-}\mathbf{B})^{-1}\mathbf{C}$

This was the equation used in Reinert, Roland-Holst, and Shiells (1993). For our purposes here, however, we take the decomposition one step further.

$$\mathbf{y}_m = (\mathbf{I}\text{-}\mathbf{D}^2)^{-1} (\mathbf{I}+\mathbf{D}) (\mathbf{I}\text{-}\mathbf{B})^{-1}\mathbf{x}$$

$$\mathbf{y}_m = \mathbf{M}_3\, \mathbf{M}_2\, \mathbf{M}_1\, \mathbf{x} \tag{7}$$

Let us interpret equation (7). Matrix $\mathbf{M}_1$ can be written as follows:

$$M_1 = \begin{bmatrix} (I - A_{11})^{-1} & 0 & 0 \\ 0 & (I - A_{22})^{-1} & 0 \\ 0 & 0 & (I - A_{33})^{-1} \end{bmatrix}$$

[5] Alternative decompositions are considered in Sonis, Hewings and Sulistyowati (1997).

This is a block diagonal matrix of *intra-country multiplier* matrices, one for each country. The diagonal blocks correspond to the multipliers that would be obtained from three single-country SAMs studied in isolation.[6]

Matrix $\mathbf{M}_2$ can be written as follows:

$$M_2 = \begin{bmatrix} I & (I-A_{11})^{-1}A_{12} & (I-A_{11})^{-1}A_{13} \\ (I-A_{22})^{-1}A_{21} & I & (I-A_{22})^{-1}A_{23} \\ (I-A_{33})^{-1}A_{31} & (I-A_{33})^{-1}A_{32} & I \end{bmatrix}$$

This matrix contains what we term *direct inter-country effects* within North America. These consist of income effects transmitted from an endogenous account in one country directly to an endogenous account in another country. These direct effects are one component of the inter-country income effects captured by multi-country general equilibrium models.

Finally, matrix $\mathbf{M}_3$ can be written as:

$$M_3 = \begin{bmatrix} \left\{I-(I-A_{11})^{-1}A_{12}(I-A_{22})^{-1}A_{21}-(I-A_{11})^{-1}A_{13}(I-A_{33})^{-1}A_{31}\right\} & -(I-A_{11})^{-1}A_{12}(I-A_{22})^{-1}A_{23} \\ -(I-A_{22})^{-1}A_{23}(I-A_{33})^{-1}A_{31} & -(I-A_{22})^{-1}A_{21}(I-A_{11})^{-1}A_{13} \\ -(I-A_{33})^{-1}A_{32}(I-A_{22})^{-1}A_{21} & \left\{I-(I-A_{33})^{-1}A_{31}(I-A_{11})^{-1}A_{13}-(I-A_{33})^{-1}A_{32}(I-A_{22})^{-1}A_{23}\right\} \end{bmatrix}$$

$$\begin{matrix} -(I-A_{11})^{-1}A_{13}(I-A_{33})^{-1}A_{32} \\ \left\{I-(I-A_{22})^{-1}A_{21}(I-A_{11})^{-1}A_{12}-(I-A_{22})^{-1}A_{23}(I-A_{33})^{-1}A_{32}\right\} \\ -(I-A_{33})^{-1}A_{31}(I-A_{11})^{-1}A_{12} \end{matrix}$$

$$\begin{matrix} -(I-A_{11})^{-1}A_{12}(I-A_{22})^{-1}A_{23} \\ -(I-A_{22})^{-1}A_{21}(I-A_{11})^{-1}A_{13} \\ \left\{I-(I-A_{33})^{-1}A_{31}(I-A_{11})^{-1}A_{13}-(I-A_{33})^{-1}A_{32}(I-A_{22})^{-1}A_{23}\right\} \end{matrix} \Bigg]^{-1}$$

[6] Roland-Holst (1990) has shown that SAM-based multipliers can differ in significant ways from

This matrix contains what we term *indirect inter-country effects* within North America, a second component of the inter-country income effects captured by multi-country general equilibrium models. It measures the income effects that are transferred from an endogenous account in one country, indirectly through a second country, to either the originating country or a third country.

Equation 7 can be rewritten as:

$$\mathbf{y}_m = [\mathbf{I} + (\mathbf{M}_1 - \mathbf{I}) + (\mathbf{M}_2 - \mathbf{I})\,\mathbf{M}_1 + (\mathbf{M}_3 - \mathbf{I})\,\mathbf{M}_2\,\mathbf{M}_1]\,\mathbf{x}$$
$$= (\mathbf{I} + \mathbf{N}_1 + \mathbf{N}_2 + \mathbf{N}_3)\,\mathbf{x} \qquad (8)$$

Equation 8 is an additive multiplier decomposition. It begins with the effects of the injection itself (the matrix $\mathbf{I}$). The matrix $\mathbf{N}_1 = (\mathbf{M}_1 - \mathbf{I})$ gives the intra-country effects net of the injection itself. The matrix $\mathbf{N}_2 = (\mathbf{M}_2 - \mathbf{I})\,\mathbf{M}_1$ gives the direct inter-country effects net of the intra-country effects. Finally, the matrix $\mathbf{N}_3 = (\mathbf{M}_3 - \mathbf{I})\,\mathbf{M}_2\,\mathbf{M}_1$ gives the indirect inter-country effects net of the direct inter-country and intra-country effects.

Perhaps some further intuition would be helpful here. Direct inter-country effects transmit an exogenous income effect in one country to another country via trade transactions. An increase in exogenous demand for agricultural goods in the United States has a positive impact on incomes in the agricultural sector in Mexico via the imports of agricultural goods by the United States from Mexico. Indirect inter-country effects are different. Trade transactions are involved twice. In one possible example, an increase in exogenous demand for transportation equipment in the United States has a positive impact on incomes in the transportation equipment sector in Mexico via the imports of transportation equipment by the United States from Canada, which, in turn,

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input-output multipliers. See also Pyatt (1999).

stimulate the imports of transportation equipment imports by Canada from Mexico. In this case, increased incomes in Canada play an intermediate role.

Given the derivation above, direct and indirect inter-country effects can be combined with the satellite account data to determine the industrial pollution linkages within the North American region.[7] The results of such an analysis are presented in the following section.

Results

In implementing the multiplier analysis, we must first decide which accounts are to be treated as endogenous and which are to be treated as exogenous. We follow Pyatt and Round (1979) in assuming that the commodity accounts, non-tax, value-added accounts and the enterprise accounts for each county are endogenous. Pyatt and Round assume that the household account is endogenous, while the government and capital accounts are exogenous. In our North American SAM, these accounts are aggregated into three domestic final demand accounts, one for each country. For this reason, we calculate multipliers twice, once with the domestic final demand accounts as exogenous and a second time with the domestic final demand accounts as endogenous. We follow Pyatt and Round in assuming that the rest of the world account, the tariff accounts, and the value-added tax accounts are exogenous. To conserve space, we report only the results for the case where the domestic final demand accounts are exogenous and provide a multiplication factor in each table for the case where the domestic final demand accounts are endogenous. Additionally, in order to keep the presentation of results simple, we focus on multipliers that are the most significant in magnitude.

Tables 1 and 2 report the direct inter-country, industrial pollution linkages transmitted from Canada and Mexico, respectively, to the United States for the nine IPPS pollutants and seventeen industrial sectors. These values are relatively large due to the high propensities of both Canada and Mexico to import from the United States. Overall, the results in this table point to the importance of detail along *all three* of the country, pollutant, and sectoral dimensions.

Although similar, the pollution linkages from Canada and Mexico to the United States differ. Both countries have significant linkages in the paper, chemical, base metals, and non-metalic mineral sectors. Mexico, however, has very significant linkages in petroleum sector, which have been the subject of some discussion in the NAFTA and environment debate.[8] Across pollutants, the sectors in which the largest direct linkages occurs can differ between Canada and Mexico. For example, in the case of NO2, the largest pollution linkages from Canada and Mexico occur in the chemical and petroleum sectors, respectively. In the case of biological oxygen demand, the largest pollution linkages from Canada and Mexico occur in the chemical and paper sectors, respectively. For a given pollutant, rankings can also change. For example, the largest particulates linkage from Canada is in the non-metalic mineral product sector, while the largest such linkage from Mexico is in the base metals sector.

Tables 3 and 4 report the direct inter-country, industrial pollution linkages transmitted from the United States to Canada and Mexico, respectively. Overall, these linkages are smaller than those in Tables 1 and 2, and this reflects the relatively low propensity of the United States to import from its two North American partners. The

[7] More detailed multipliers are presented in Reinert, Ricaurte, and Roland-Holst (1998).
[8] See Commission for Environmental Cooperation (1996).

linkages in Tables 3 and 4 are very much concentrated in the petroleum and base metal sectors. Additionally, the paper sector plays a large role as a pollution linkage from the United States to Canada. For biological oxygen demand, the food processing and beverages sectors are important as a pollution linkage from the United States to Mexico.

A final important result in the area of water pollution is visible across Tables 1 to 4. The base metals sector plays a significant role in transmitting total suspended solids pollution across borders in North America. This would seem to constitute an area of concern for policymakers worried about contributions of North American economic integration to water pollution levels.

Tables 5, 6, and 7 report the indirect inter-country, industrial pollution linkages transmitted from Canada, the United States, and Mexico, respectively, through their two trading partners, and back onto themselves. As with the direct inter-country effects, these tables suggest that detail along all three of the country, pollutant, and sectoral dimensions is important. For the United States and Mexico, base metals and petroleum are the sectors with the strongest, indirect pollution linkages. For Canada, the pattern is somewhat different, with petroleum playing a less important role. Chemicals and paper feature strongly in both Canada and the United States in generating indirect inter-country pollution linkages, but this is not the case for Mexico. For volatile organic compounds and toxins, the transportation equipment sector generates significant indirect pollution linkages in Canada and the United States, but again this is not the case for Mexico.

A final comment on the endogeneity factors reported in Tables 1 to 7 is in order. Recall that these reflect the increase in pollution linkages that result from making the domestic final demand (household, investment, and government) accounts endogenous in the multiplier analysis. These show some significant degree of dispersion. Consequently, it is possible that sectoral rankings of some pollution linkages could change when these factors are applied. In Table 1, for example, the endogeneity of final demand makes the particulate linkage from Canada to the United States more important than the chemicals linkage. Policy analysts making use of Tables 1 through 7 will want to keep such possibilities in mind.[9]

Summary

The results presented in Tables 1 through 7 should be read with some reservation. In particular, they are limited by the approximate nature of the IPPS data, the 1991 SAM described in the appendix, and the linear nature of the linkage calculations. However, Hettige, Lucas, and Wheeler (1992) report that "sector ranking by toxic intensity has remained approximately constant across the OECD countries during the past two decaded" (p. 478). Consequently, the results presented in Tables 1 through 7 are a useful ordinal device in detecting those sectors where the expansion and continuing integration of the three North American counties will generate strong pollution linkages. In particular, these results capture the ways that sectoral pollution intensities interact with input-output and trade linkages within the North American economy. The importance of these interactions is illustrated by the fact that most relevant sector/pollutant combinations differ somewhat among the three countries.

We hope that the work presented in this paper will help policy analysts isolate the most relevant sectors within North America for developing sound trade and the

[9] That said, the inclusion of investment and government spending in domestic final demand, make the endogeneity factors *overestimates* in comparison to any realistic multiplier values.

environment policies. In particular, we hope that the results of Tables 1 through 7 will contribute to the ongoing discussions of the impact of NAFTA on the environment and to the work of relevant organizations such as the Montreal-based Commission for Environmental Cooperation (CEC).

Appendix: SAM Construction

This appendix provides a brief description of the construction of the 1991 social accounting matrix (SAM) of North America.[10] Construction of the 1991 North American SAM began with the transformation of 1991 national accounts for each country into three separate macroeconomic SAMs. For this purpose, Canadian macroeconomic data were taken from Statistics Canada (1993a and 1993b), U.S. macroeconomic data were taken from U.S. Department of Commerce (1992), and Mexican macroeconomic data were taken from OECD (1992), Banco de México (1993), Instituto National de Estadística, Geographía e Informática (1992), and International Monetary Fund (1993). Next, individual macroeconomic SAMs were joined together into a North American macroeconomic SAM using market exchange rates from International Monetary Fund (1993) and aggregate trade flows taken from International Monetary Fund (1992). Adjustments for maquiladora trade were made with data from Banco de México (1993), and factor service and capital flows were added using data from U.S. Department of Commerce (1992) and Statistics Canada (1993b).

The next stage of SAM construction involved estimation of the 26 sectoral accounts of each country. Labor value added, property value added, indirect business

[10] For the interested reader, a more detailed description of the SAM is available from the authors upon request.

taxes, value added taxes (for Mexico), domestic final demand, imports, exports, and inter-industry transactions were disaggregated for each country into the 26 sectors. For labor value added, property value added, indirect business taxes, value added taxes, and domestic final demand, this was done using shares from input-output accounts. For Canada, we used 1990 Statistics Canada input output accounts. For the United States, we used 1987 U.S. Department of Labor input-output accounts.[11] In the case of Mexico, we used 1989 SECOFI input output accounts.[12] For imports and exports, the disaggregation was conducted using 10-digit HTS data for the United States and 3-digit SITC data for all three countries. The former were obtained from U.S. Department of Commerce data tapes, and the latter were obtained from United Nations data tapes. Canadian tariffs were estimated from the 1990 input-output data, U.S. tariffs were estimated from the Department of Commerce data, and Mexican tariffs were estimated from data presented in General Agreement on Tariffs and Trade (1993).

For Canada and the United States, 1991 interindustry transactions were estimated using make and use tables for 1990 and 1987, respectively. Make and use tables were balanced using 1991 gross activity output and the RAS procedure.[13] We then removed activity accounts using the Pyatt (1985) procedure. For Mexico, the 1989 transactions matrix was updated to 1991 using 1991 value added, final demand, import and export data.

[11] These are census based. At the time of the work on the SAM, the 1987 U.S. Department of Commerce input-output accounts were not available.
[12] SECOFI is the acronym for Secretaría de Comercio y Fomento Industrial.
[13] On the RAS procedure, see Schneider and Zenios (1990).

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Table 1. Direct Inter-country Industrial Pollution Linkages from Canada to the United States (pounds per 1991 US$1 million of new, exogenous demand in Canada)

	Air	Air	Air	Air	Air			Water	Water	Engog.
Sector	**PT**	**CO**	**CO2**	**NO2**	**VOC**	**Metals**	**Toxins**	**BOD**	**TSS**	**Factor**
petrol	147	265	542	327	161	1	61	3	13	4.1
foodpr	82	25	90	90	23	0	18	123	31	3.0
bever	2	2	32	20	34	0	2	14	25	2.6
tobac	0	1	10	6	2	0	2	0	0	2.8
textl	57	50	273	359	164	7	198	11	17	1.2
cloth	0	0	5	2	1	0	3	0	0	1.3
leath	13	10	58	72	39	4	64	4	6	1.0
paper	106	620	541	299	148	1	194	290	976	2.0
chem	219	2187	1128	1072	927	73	2481	255	958	1.7
rubber	35	13	305	105	407	35	467	67	166	1.2
nmtmn	1111	196	1534	982	68	9	97	2	28	1.3
bsmetl	707	4448	5004	942	371	986	1632	236	24532	1.2
wdmetl	148	258	59	111	360	12	141	4	31	2.2
nelcmc	22	163	150	68	171	31	184	1	12	1.2
elcmc	21	108	197	97	132	46	369	8	11	1.5
trnseq	30	51	73	38	271	11	209	0	1	1.7
othmn	5	2	9	9	55	9	132	0	1236	1.3

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds; Metals- metals to air, water, and land; Toxins- toxins to air, water, and land; BOD- biological oxygen demand; and TSS- total suspended solids.
Endogeneity Factor: the value by which to multiply table entries in moving from the case where domestic final demand is exogenous to the case where domestic final demand is endogenous.

Table 2. Direct Inter-country Industrial Pollution Linkages from Mexico to the United States (pounds per 1991 US$1 million of new, exogenous demand in Mexico)

	Air	Air	Air	Air	Air			Water	Water	Endog.
Sector	**PT**	**CO**	**CO2**	**NO2**	**VOC**	**Metals**	**Toxins**	**BOD**	**TSS**	**Factor**
petrol	752	1353	2765	1671	822	1020	310	15	68	1.8
foodpr	79	23	86	86	22	17	18	117	29	3.4
bever	1	1	15	9	16	0	1	6	12	4.8
tobac	0	0	0	0	0	0	0	0	0	NA
textl	27	24	128	168	77	45	93	5	8	1.4
cloth	0	1	5	2	1	2	3	0	0	1.3
leath	12	9	50	62	34	11	55	3	5	1.1
paper	166	970	848	468	232	296	304	455	1529	1.7
chem	149	1486	767	728	630	338	1686	173	651	2.0
rubber	28	10	242	83	324	156	371	53	132	1.3
nmtmn	333	59	460	295	20	30	29	1	8	1.9
bsmetl	665	4186	4710	887	349	1237	1536	223	23089	1.2
wdmetl	234	409	93	176	571	180	224	6	49	1.8
nelcmc	24	176	162	73	185	194	199	1	13	1.2
elcmc	18	94	171	84	114	116	321	7	9	1.5
trnseq	35	59	84	44	313	158	241	0	1	1.7
othmn	3	1	5	4	28	6	68	0	642	1.6

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds; Metals- metals to air, water, and land; Toxins- toxins to air, water, and land; BOD- biological oxygen demand; and TSS- total suspended solids.
Endogeneity Factor: the value by which to multiply table entries in moving from the case where domestic final demand is exogenous to the case where domestic final demand is endogenous.

Table 3. Direct Inter-country Industrial Pollution Linkages from the United States to Canada (pounds per 1991 US$1 million of new, exogenous demand in the United States)

	Air	Air	Air	Air	Air			Water	Water	Endog.
Sector	PT	CO	CO2	NO2	VOC	Metals	Toxins	BOD	TSS	Factor
petrol	287	516	1055	637	313	2	118	6	26	1.4
foodpr	8	2	9	9	2	0	2	12	3	3.7
bever	1	1	19	12	20	0	1	8	14	1.5
tobac	0	0	4	3	1	0	1	0	0	1.3
textl	2	1	7	10	4	0	5	0	0	1.6
cloth	0	0	0	0	0	0	0	0	0	2.0
leath	1	0	3	3	2	0	3	0	0	1.5
paper	57	330	288	159	79	0	103	155	520	1.5
chem	2	19	10	9	8	1	21	2	8	2.0
rubber	3	1	24	8	32	3	37	5	13	1.3
nmtmn	154	27	212	136	9	1	13	0	4	1.3
bsmetl	211	1328	1495	281	111	294	487	71	7326	1.1
wdmetl	36	63	14	27	88	3	35	1	8	1.9
nelcmc	1	10	9	4	10	2	11	0	1	1.6
elcmc	2	8	14	7	9	3	26	1	1	1.8
trnseq	9	15	22	11	82	3	63	0	0	1.6
othmn	0	0	0	0	1	0	3	0	30	1.7

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds; Metals- metals to air, water, and land; Toxins- toxins to air, water, and land; BOD- biological oxygen demand; and TSS- total suspended solids.
Endogeneity Factor: the value by which to multiply table entries in moving from the case where domestic final demand is exogenous to the case where domestic final demand is endogenous.

Table 4. Direct Inter-country Industrial Pollution Linkages from the United States to Mexico (pounds per 1991 US$1 million of new, exogenous demand in the United States)

	Air	Air	Air	Air	Air			Water	Water	Endog.
Sector	**PT**	**CO**	**CO2**	**NO2**	**VOC**	**Metals**	**Toxins**	**BOD**	**TSS**	**Factor**
petrol	116	209	428	258	127	1	48	2	10	1.3
foodpr	30	9	32	32	8	0	7	44	11	0.7
bever	5	4	80	51	87	1	6	34	62	0.2
tobac	0	0	1	1	0	0	0	0	0	1.0
textl	3	2	13	17	8	0	9	1	1	1.3
cloth	0	0	0	0	0	0	0	0	0	1.4
leath	2	2	9	11	6	1	9	1	1	1.1
paper	2	10	9	5	2	0	3	5	16	2.5
chem	3	28	14	14	12	1	32	3	12	3.7
rubber	0	0	4	1	5	0	6	1	2	1.5
nmtmn	85	15	118	76	5	1	7	0	2	1.3
bsmetl	32	201	226	43	17	45	74	11	1110	1.3
wdmetl	9	15	3	7	21	1	8	0	2	1.9
nelcmc	0	2	2	1	2	0	2	0	0	1.8
elcmc	2	8	15	7	10	3	28	1	1	1.3
trnseq	1	2	3	2	11	0	9	0	0	1.7
othmn	0	0	0	0	1	0	3	0	30	1.3

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds; Metals- metals to air, water, and land; Toxins- toxins to air, water, and land; BOD- biological oxygen demand; and TSS- total suspended solids.
Endogeneity Factor: the value by which to multiply table entries in moving from the case where domestic final demand is exogenous to the case where domestic final demand is endogenous.

Table 5. Indirect Inter-country Industrial Pollution Linkages from Canada to Canada (pounds per 1991 US$1 million of new, exogenous demand in Canada)

	Air	Air	Air	Air	Air			Water	Water	Endog.
Sector	PT	CO	CO2	NO2	VOC	Metals	Toxins	BOD	TSS	Factor
petrol	8	14	29	17	8	0	3	0	1	7.5
foodpr	1	0	1	1	0	0	0	1	0	12.0
bever	0	0	0	0	0	0	0	0	0	NA
tobac	0	0	0	0	0	0	0	0	0	NA
textl	0	0	1	1	1	0	1	0	0	3.0
cloth	0	0	0	0	0	0	0	0	0	3.0
leath	0	0	0	0	0	0	0	0	0	NA
paper	5	30	27	15	7	0	10	14	48	3.5
chem	4	37	19	18	16	0	42	4	16	3.3
rubber	1	0	7	2	9	0	11	2	4	1.6
nmtmn	17	3	24	15	1	0	1	0	0	2.5
bsmetl	42	262	294	55	22	5	96	14	1443	1.4
wdmetl	4	8	2	3	11	0	4	0	1	4.5
nelcmc	1	4	4	2	4	0	5	0	0	1.9
elcmc	0	2	4	2	3	0	8	0	0	2.5
trnseq	3	5	7	4	25	1	20	0	0	2.2
othmn	0	0	0	0	0	0	1	0	9	2.5

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds; Metals- metals to air, water, and land; Toxins- toxins to air, water, and land; BOD- biological oxygen demand; and TSS- total suspended solids.
Endogeneity Factor: the value by which to multiply table entries in moving from the case where domestic final demand is exogenous to the case where domestic final demand is endogenous.

Table 6. Indirect Inter-country Industrial Pollution Linkages from the United States to the United States (pounds per 1991 US$1 million of new, exogenous demand in the United States)

Sector	Air PT	Air CO	Air CO2	Air NO2	Air VOC	Metals	Toxins	Water BOD	Water TSS	Endog. Factor
petrol	27	49	100	60	30	0	11	1	2	5.3
foodpr	1	0	1	1	0	0	0	1	0	33.0
bever	0	0	0	0	0	0	0	0	0	NA
tobac	0	0	0	0	0	0	0	0	0	NA
textl	1	1	3	4	2	0	2	0	0	4.0
cloth	0	0	0	0	0	0	0	0	0	4.5
leath	0	0	1	1	0	0	1	0	0	2.0
paper	5	30	27	15	7	0	10	14	48	5.7
chem	5	47	24	23	20	2	53	5	20	6.8
rubber	1	0	8	3	11	1	12	2	4	2.6
nmtmn	26	5	35	23	2	0	2	0	1	3.3
bsmetl	51	322	362	68	27	71	118	17	1776	1.7
wdmetl	7	11	3	5	16	1	6	0	1	6.8
nelcmc	1	5	5	2	5	1	6	0	0	2.5
elcmc	1	5	9	5	6	2	17	0	1	3.2
trnseq	3	5	7	3	24	1	19	0	0	3.2
othmn	0	0	0	0	1	0	1	0	13	6.0

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds; Metals- metals to air, water, and land; Toxins- toxins to air, water, and land; BOD- biological oxygen demand; and TSS- total suspended solids.
Endogeneity Factor: the value by which to multiply table entries in moving from the case where domestic final demand is exogenous to the case where domestic final demand is endogenous.

Table 7. Indirect Inter-country Industrial Pollution Linkages from Mexico to Mexico (pounds per 1991 US$1 million of new, exogenous demand in the Mexico)

	Air	Air	Air	Air	Air			Water	Water	Endog.
Sector	**PT**	**CO**	**CO2**	**NO2**	**VOC**	**Metals**	**Toxins**	**BOD**	**TSS**	**Factor**
petrol	16	28	57	34	17	0	6	0	1	2.3
foodpr	0	0	0	0	0	0	0	0	0	NA
bever	0	0	0	0	0	0	0	0	0	NA
tobac	0	0	0	0	0	0	0	0	0	NA
textl	0	0	1	1	1	0	1	0	0	2.0
cloth	0	0	0	0	0	0	0	0	0	1.5
leath	0	0	1	1	0	0	1	0	0	2.0
paper	0	0	0	0	0	0	0	0	0	NA
chem	0	0	0	0	0	0	0	0	0	NA
rubber	0	0	1	0	1	0	2	0	1	2.0
nmtmn	0	0	0	0	0	0	0	0	0	NA
bsmetl	6	40	45	9	3	9	15	2	222	2.3
wdmetl	2	4	1	2	5	0	2	0	0	2.5
nelcmc	0	1	1	0	1	0	1	0	0	2.5
elcmc	0	2	4	2	3	1	7	0	0	1.9
trnseq	0	1	1	1	4	0	3	0	0	2.2
othmn	0	0	0	0	0	0	0	0	4	2.0

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds; Metals- metals to air, water, and land; Toxins- toxins to air, water, and land; BOD- biological oxygen demand; and TSS- total suspended solids.
Endogeneity Factor: the value by which to multiply table entries in moving from the case where domestic final demand is exogenous to the case where domestic final demand is endogenous.

Appendix B

The Industrial Pollution Impacts of NAFTA:

Some Preliminary Results

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Paper prepared for the North American Symposium on Understanding the Linkages between Trade and Environment

Commission for Environmental Cooperation

11-12 October 2000

Revised November 2000

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The Industrial Pollution Impacts of NAFTA: Some Preliminary Results

Abstract. In this paper, we use a three-country trade model of the North American economy, along with data from the World Bank's Industrial Pollution Projection System (IPPS), to simulate the potential industrial pollution impacts of NAFTA. We find that the most serious industrial pollution impacts occur in the base metals sector. The Mexican petroleum sector is also a significant source of industrial pollution, particularly in the case of air pollution. For specific pollutants in specific countries, the transportation equipment sector is an important source of industrial pollution. Finally, the chemical sector is a significant source of industrial toxin pollution in the United States and Mexico, but not in Canada.

Introduction

The policy debates surrounding the negotiation, passage, and assessment of the North American Free Trade Area (NAFTA) has focused to a great extent on the linkages between trade and the environment.[1] To a large degree, however, this debate has been more speculative than empirical. This is unfortunate because it is well known that *a priori* reasoning alone cannot predict whether trade liberalization will have an overall positive or negative impact on the environment.[2] This paper attempts to provide some empirical evidence in the area of industrial pollution to better inform future debate.

One study that does provide some empirical evidence on NAFTA and the environment was conducted by Grossman and Krueger (1993). These authors combined the output effects of NAFTA as simulated by Brown, Deardorff and Stern (1992) with data from the U.S. Environmental Protection Agency on toxic pollution. With regard to the *direct* impacts of trade liberalization (as opposed to liberalization-induced increases in investment), these authors found that the greatest increases in toxic pollution occur in the U.S. chemicals sector and the Canadian base metals and rubber and plastics products sectors. Other significant trade-induced increases in toxic pollution occurred in the

[1] For a definitive review, see Johnson and Beaulieu (1996).

[2] See Runge (1994), Beghin and Potier (1997), and Beghin, Roland-Holst, and van der Mensbrugghe (1997).

Mexican electrical equipment sector, the U.S. paper products sector, and the Canadian transportation equipment sector.[3]

In this paper, we focus on the industrial pollution impacts of NAFTA. We utilize a three-country, applied equilibrium (AGE) trade model of the North American economy and make use of the World Bank's Industrial Pollution Projection System (IPPS) to generate results for a detailed set of industrial sectors and pollutants. We simulate the liberalization of tariffs and non-tariff barriers (NTBs) that have accompanied NAFTA and provide results for the changes in emissions by industrial sector and pollutant. The results allow us to identify where some of the major environmental impacts of NAFTA might be found.

The Trade Model

We employ a standard applied general equilibrium (AGE) trade model used to simulate the industrial pollution effects of North American trade liberalization in 17 industrial sectors of Canada, the United States, and Mexico.[4] The trade specification follows that of de Melo and Robinson (1989). In each sector of each country, domestic demand is constituted of goods that are differentiated by origin (domestic good, imports from each North American trading partner, and imports from the rest of the world). Also in each sector of each country, domestic production is allocated among differentiated destinations (domestic good, exports to each North American trading partner, and exports to the rest of the world). World prices outside of North America are assumed to remain constant, exchange rates are assumed to be flexible, and trade balances are fixed.

Production in each sector of each country utilizes physical capital and labor. These factors are assumed to be perfectly mobile among the sectors of each country but immobile among countries. Production takes place under constant returns to scale and intermediate goods are utilized in fixed proportions to value added. All markets are perfectly competitive.

The trade-liberalizing experiments we conduct use observed tariff rates for our base year 1991. In addition, we consider very rough estimates of non-tariff barriers using

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[3] See also Abler and Pick (1993) for a focus on the Mexican horticultural sector.
[4] Model equations are presented in the Appendix.

UNCTAD data on trade control measures. As is general practice (e.g. Gaston and Trefler, 1994), we use NTB coverage ratios as *ad valorem* equivalents. For this reason, our simulations must be interpreted as merely *suggestive* of the impacts of NAFTA on trade, production, and pollution.[5]

The three-country trade model is calibrated to a 1991 base year data set.[6] The IPPS effluent data are used to create *satellite environmental accounts* to this data set as suggested by Barker (1992), United Nations (1993a,b), and de Haan and Keuning (1996). As is recommended by their compilers, IPPS effluent data are utilized in their per-employee form. Table 1 describes the IPPS pollutants. [7] In the case of air pollution, the IPPS data include particulates, carbon monoxide, sulfur dioxide, nitrogen dioxide, and volatile organic compounds. In the case of industrial bio-accumulative metals and toxins, the data distinguish among transmission to air, water, and land. Finally, in the case of water pollution, the data distinguish between biological oxygen demand and total suspended solids.

Simulation Results

For the purposes of this paper, we focus on a simulation exercise closest to that considered by Brown, Deardorff and Stern (1992) and, therefore, by Grossman and Krueger (1993).[8] We consider the removal of both tariffs as measured by their observed values and NTBs as measured by coverage ratios. We assume that each North American trading partner maintains its existing protection with respect to the rest of the world. Additionally, as is standard practice in most trade policy models, we assume that total labor supply is fixed in each country. The results of these simulations for each industrial

[5] The NTB measures are discussed in Roland-Holst, Reinert, and Shiells (1994).
[6] The base year data set is in the form of a social accounting matrix (SAM) described in a document available from the corresponding author and (for Spanish speakers) in Reinert, Ricaurte, and Roland-Holst (1998). The calibration of the model also requires a set of behavior parameters described in Reinert and Roland-Holst (1998), and these behavioral parameters can be varied to conduct sensitivity analyses.
[7] On the IPPS, see Hettige, Lucas and Wheeler (1992) and the references therein. See also the web-site listed in our data sources at the end of the paper.
[8] As with all AGE simulations, the results are not forecasts. Rather they simulate a *counterfactual* economy, namely, North America in 1991 with the NAFTA trade liberalization agreements fully in place.

sector and IPPS pollutant are presented in Tables 2 through 5. For comparison purposes, estimated base-level emissions are presented in Tables 6 through 9.

Table 2 presents the changes in industrial *air pollution* caused by trade liberalization in North America for each industrial sector of the model. The evidence presented in this table suggests that the industrial air pollution generated as a result of NAFTA will be concentrated in a few particular sectors. These are petroleum, base metals, and transportation equipment. For particulates, carbon monoxide, sulfur dioxide, and nitrogen dioxide, the greatest increases occur in the U.S. base metals sector and in the Mexican petroleum sector.[9] In the case of volatile organic compounds, however, the transportation equipment sectors of Canada and the United States are large sources. In terms of total air pollution emissions, the greatest increases are of carbon monoxide and sulfur dioxide in the United States and sulfur dioxide in Mexico. Significant reductions in air pollution occur in the Canadian and Mexican paper sectors and in the Canadian chemicals sector.

Table 3 addresses industrial *bio-accumulative metals pollution.* Here, the petroleum sector plays a less important role than base metals and transportation equipment. The largest emissions are to land, and these occur in the Canadian and U.S. base metals and transportation equipment sectors and in the Mexican base metals sector. In terms of total emissions, the United States leads both Canada and Mexico, primarily as a result of changes in its base metals sector. Again the Canadian chemicals sector registers improvement in emissions, although these are slight.

Table 4 presents the changes in industrial *toxin pollution.* Here, transmission to air is important along with transmission to land. This is especially the case for the transportation equipment sector in Canada. The base metals sector is also important for the transmission of toxins to land in this country.[10] In the United States and Mexico, the chemical sector appears as significant sources of toxins. Importantly, this is *not* the case

[9] Pollution associated with the petroleum sector in Mexico has been a significant part of the debate over NAFTA and the environment. See Commission for Environmental Cooperation (1996).

[10] Qualitatively, these results for Canada agree with those of Grossman and Krueger (1993).

for Canada where this is a *reduction* of toxin emissions in the chemical sector.[11] This reflects the comparative advantage of the U.S. and Mexican chemical sectors over their Canadian counterpart. The U.S. base metals and transportation equipment sectors and the Mexican petroleum sector are also significant sources of toxins, [12] and in terms of total emissions, the U.S. leads with toxic emissions to land and air.

Finally, Table 5 presents the simulation results for *water pollution*. The base metals sector is again a crucial source of effluents. This is particularly the case for total suspended solids in all three countries. In the case of biological oxygen demand, there is actually an overall decrease in Canada due to the contraction of the paper products sector. The Mexican petroleum sector is a significant source of total suspended solids, but this is an order of magnitude less than in its base metals sector. By far, the greatest concern with regard to water pollution as a result of NAFTA trade liberalization is the increase in total suspended solids from the base metals sector of the United States.

Conclusions

The most serious industrial pollution impacts of NAFTA occur in the base metals sector. In terms of magnitude, the greatest impacts are in the United States and Canada, and this is the case for most of the pollutants considered. As alleged in the debate over NAFTA and the environment, however, the Mexican petroleum sector is a significant source of industrial pollution, particularly in the case of air pollution. For specific industrial pollutants in specific countries, the transportation equipment sector is also an important source of industrial pollution. This is the case for both volatile organic compounds and toxins released into the air in Canada and the United States. Finally, as suggested by Grossman and Krueger's (1993) results, the chemical sector is a significant source of industrial toxin pollution in the United States and Mexico, but not in Canada.

It is hoped that the results of this paper will contribute to the ongoing discussions of the impacts of NAFTA on the environment in general and to the work of the Commission for Environmental Cooperation (CEC) in particular.

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[11] Grossman and Krueger (1993) show a decrease in toxin pollution from the Mexican chemicals sector in their trade-liberalization alone case, but an increase in the trade and investment liberalization case.

Appendix: Trade Model Equations

This appendix presents the equation structure for a simple, multi-region applied general equilibrium model of trade policy. The equations of the model are presented first, and these are followed by a description of the variables and parameters. The equation that determines each variable is given in parentheses after its definition. To simplify the model, all markets are perfectly competitive, there are constant returns to scale in production, quota rents accrue to domestic importers, and supplies of labor and physical capital are fixed in each region.

Consumer Behavior (LES)

$$P_{ij}^{Q} C_{ij} = P_{ij}^{Q} \mu_{ij} + s_{ij} \left(Y_j - \sum_h P_{hj}^{Q} \mu_{hj} \right) \qquad \forall i, j \tag{1}$$

Cost Equations and Production (CES with Leontief Intermediates)

$$V_{ij} = \left(\frac{X_{ij}}{a_{ij}} \right) \left[b_{ij}^{\phi_{ij}} w_j^{(1-\phi_{ij})} + \left(1 - b_{ij}^{\phi_{ij}}\right) r_j^{(1-\phi_{ij})} \right]^{\frac{1}{(1-\phi_{ij})}} \qquad \forall i, j \tag{2}$$

$$T_{ij} = V_{ij} + \sum_h P_{hj}^{Q} io_{hij} X_{ij} \qquad \forall i, j \tag{3}$$

Factor Markets (CES Demands and Full Employment)

$$L_{ij} = V_{ij}^{\phi_{ij}} X_{ij}^{(1-\phi_{ij})} b_{ij}^{\phi_{ij}} w_j^{-\phi_{ij}} a_{ij}^{(\phi_{ij}-1)} \qquad \forall i, j \tag{4}$$

$$K_{ij} = V_{ij}^{\phi_{ij}} X_{ij}^{(1-\phi_{ij})} \left(1 - b_{ij}\right)^{\phi_{ij}} r_j^{-\phi_{ij}} a_{ij}^{(\phi_{ij}-1)} \qquad \forall i, j \tag{5}$$

$$\sum_i L_{ij} = L_j \qquad \forall j \tag{6}$$

$$\sum_i K_{ij} = K_j \qquad \forall j \tag{7}$$

[12] Here, our results are in contradiction to those of Grossman and Krueger (1993). This is most likely due to the different way we model NTBs compared to Brown, Deardorff and Stern (1992).

Commodity Demands, Supplies, and Allocation of Traded Goods (CES and CET)

$$Q_{ij} = \alpha_{ij}\left[\sum_k \beta_{ijk} D_{ijk}^{\frac{(\sigma_{ij}-1)}{\sigma_{ij}}}\right]^{\frac{\sigma_{ij}}{(\sigma_{ij}-1)}} \qquad \forall i,j \tag{8}$$

$$\left(\frac{D_{ijk}}{D_{ijj}}\right) = \left[\left(\frac{\beta_{ijk}}{\beta_{ijj}}\right)\left(\frac{P_{ijj}}{P_{ijk}}\right)\right]^{\sigma_{ij}} \qquad \forall i,j,k,j \neq k \tag{9}$$

$$X_{ij} = \gamma_{ij}\left[\sum_k \delta_{ijk} S_{ijk}^{\frac{(\tau_{ij}+1)}{\tau_{ij}}}\right]^{\frac{\tau_{ij}}{(\tau_{ij}+1)}} \qquad \forall i,j \tag{10}$$

$$\left(\frac{S_{ijk}}{S_{ijj}}\right) = \left[\left(\frac{\delta_{ijk}}{\delta_{ijj}}\right)\left(\frac{P_{ijj}}{P_{ijk}}\right)\right]^{\sigma_{ij}} \qquad \forall i,j,k,j \neq k \tag{11}$$

Commodity Prices

$$P_{ij}^{Q} Q_{ij} = \sum_k P_{ijk} D_{ijk} \qquad \forall i,j \tag{12}$$

$$P_{ij}^{X} X_{ij} = \sum_k P_{ijk} S_{ijk} \qquad \forall i,j \tag{13}$$

$$P_{ijj} = \frac{T_{ij}}{X_{ij}} \qquad \forall i,j \tag{14}$$

$$P_{ijk} = \left(1 + t_{ijk}\right)\left(1 + \rho_{ijk}\right) e_j PW_{ijk} \qquad \forall i,j,k,j \neq k \tag{15}$$

Commodity Market Equilibrium

$$Q_{ij} = C_{ij} + \sum_h io_{ihj} X_{hj} \qquad \forall i,j \tag{16}$$

$$D_{ijk} = S_{ijk} \qquad \forall i,j,k \tag{17}$$

Income and Revenue

$$RT_j = \sum_i \sum_k t_{ijk} e_j PW_{ijk} D_{ijk} \qquad \forall j \tag{18}$$

$$RQ_j = \sum_i \sum_k \rho_{ijk} e_j PW_{ijk} D_{ijk} \qquad \forall j \tag{19}$$

$$Y_j = w_j L_j + r_j K_j + RT_j + RQ_j \qquad \forall j \tag{20}$$

Foreign Balance

$$\sum_{k \neq j} \sum_i PW_{ijk} S_{ijk} = \sum_{k \neq j} \sum_i PW_{ijk} D_{ijk} \qquad \forall j \tag{21}$$

Sets and Indices

$h, i \in I$ sectors

$j, k \in J$ regions

Quantity Variables

C_{ij} = final demand for composite consumption good *i* in region *j* (1)

D_{ijk} = demand for good i in region j from source region *k* (8, 9)

K_{ij} = input of physical capital in sector *i* of region *j* (5)

L_{ij} = input of labor in sector *i* of region *j* (4)

Q_{ij} = demand for composite consumption good *i* in region *j* (16)

S_{ijk} = supply of good *i* from region *j* to region *k* (10, 11)

X_{ij} = output of sector *i* in region *j* (14)

Price Variables

e_j = exchange rate for region *j* (21)

P_{ijk} = domestic price of good *i* in region *j* demanded from region *k* (15, 17)

P_{ij}^{Q} = domestic purchaser price of composite consumption good *i* in region *j* (12)

P_{ij}^{X} = domestic producer price of composite good i in region j (13)

PW_{ijk} = world price of good i demanded in region j from region k (17)

r_j = rental rate on physical capital in region j (7)

w_j = wage rate in region j (6)

Nominal Variables

RQ_j = quota rents in region j (19)

RT_j = tariff revenue in region j (18)

T_{ij} = total costs in sector i of region j (3)

V_{ij} = value added in sector i in region j (2)

Y_j = income in region j (20)

Parameters

a_{ij} = intercept parameter in CES production function in sector i of region j

b_{ij} = share parameter in CES production function in sector i of region j

io_{hij} = input of good h needed per unit of sector i output in region j

K_j = total physical capital stock in region j

L_j = total labor force in region j

s_{ij} = consumption share for composite good i in region j

t_{ijk} = ad valorem tariff on imports of good i into region j from region k

α_{ij} = intercept parameter in CES product aggregation function for sector i of region j

β_{ijk} = share parameter in CES product aggregation function for product i in region j from source region k

δ_{ij} = share parameter in CET allocation function for sector i in region j

γ_{ij} = intercept parameter in CET allocation function for sector i in region j

μ_{ij} = subsistence minimum for composite consumption good i in region j

ϕ_{ij} = elasticity of substitution between labor and capital in sector i of region j

ρ_{ijk} = ad valorem equivalent quota on imorts of good i into region j from region k

σ_{ij} = elasticity of substitution among sources of product i in region j

τ_{ij} = elasticity of transformation among destinations for sector i of region j

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Table 1. The IPPS Pollutants

Name	**Symbol**	**Description**
Particulates	PT	Fine airborne particles that can damage respiratory systems.
Carbon Monoxide	CO	A poisonous gas that inhibits the ability of blood to carry oxygen.
Sulfur Dioxide	SO2	A gas that can contribute to respiratory disease and acid rain.
Nitrogen Dioxide	NO2	A gas that contributes to both respiratory disease and to the formation of acid rain and ozone.
Volatile Organic Compounds	VOC	A class of chemicals associated with skin reactions, nervous system effects, sick-building syndrome, and multiple chemical sensitivity. Many are also suspected carcinogens.
Bio-accumulative Metals	MetAir, MetWat, MetLand	Metals, including mercury, lead, arsenic, chromium, nickel, copper, zinc, and cadmium. They contribute to mental and physical birth defects.
Toxic Pollutants	ToxAir, ToxWat, ToxLand	A class of chemicals that can damage internal organs and neurological functions, cause reproductive problems and birth defects. Many are also suspected carcinogens.
Biological Oxygen Demand	BOD	Organic water pollutants that remove dissolved oxygen. They can damage aquatic species and promote the growth of algae and pathogens.
Total Suspended Solids	TSS	Non-organic, non-toxic particles that can damage aquatic ecosystems and promote the growth of pathogens.

Source: World Bank Industrial Pollution Projection System

Table 2. Effects of NAFTA on Industrial Air Pollution (thousands of pounds)

	Can	Can	Can	Can	Can	US	US	US	US	US	Mex	Mex	Mex	Mex	Mex
Sector	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC
Petrol	4,384	14,077	27,710	16,248	12,220	1,067	3,426	6,743	3,954	2,974	15,322	49,196	96,840	56,783	42,705
Foodpr	325	97	354	355	92	2,782	828	3,035	3,042	791	341	101	372	372	97
Bever	25	20	383	244	414	-37	-30	-570	-363	-616	39	31	598	381	646
Tobac	2	10	123	74	24	-4	-19	-239	-145	-48	0	2	19	12	4
Textl	-55	-48	-261	-343	-157	180	158	857	1,126	515	351	309	1,674	2,199	1,007
Cloth	0	0	3	1	1	0	0	-3	-1	-1	0	0	1	0	0
Leath	11	1	20	5	35	140	18	254	64	442	8	1	14	3	24
Paper	-1,821	-10,609	-9,323	-5,141	-2,044	33	192	169	93	37	-197	-1,149	-1,009	-557	-221
Chem.	-293	-2,630	-1,552	-1,516	-1,279	1,276	11,472	6,770	6,614	5,581	845	7,598	4,484	4,381	3,696
Rubber	99	37	856	294	1,123	137	51	1,188	408	1,559	11	4	94	32	124
Nmtmn	-476	-119	-688	-541	-64	-111	-28	-160	-126	-15	1,892	475	2,735	2,150	253
Bsmetl	5,016	30,825	40,248	5,759	2,543	12,374	76,052	99,301	14,209	6,275	1,344	8,261	10,786	1,543	682
Wdmetl	637	1,159	253	493	1,325	2,920	5,314	1,162	2,261	6,077	763	1,388	304	591	1,588
Nelcmc	1	9	9	4	10	71	518	479	215	545	25	184	170	76	193
Elcmc	33	168	305	150	204	-10	-53	-96	-47	-64	36	185	337	166	226
Trnseq	3,266	5,561	7,908	4,109	29,531	3,531	6,013	8,550	4,443	31,930	294	500	711	370	2,656
Othmn	2	1	3	3	18	1	0	2	1	9	3	1	6	6	37
Total	11,156	38,558	66,352	20,199	43,997	24,349	103,913	127,442	35,750	55,991	21,076	67,088	118,136	68,509	53,716

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds.

Table 3. Effects of NAFTA on Industrial Bio-accumulative Metals Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	MetAir	MetWat	MetLand	MetAir	MetWat	MetLand	MetAir	MetWat	MetLand
Petrol	8	3	84	2	1	20	30	12	292
Foodpr	0	0	1	0	0	5	0	0	1
Bever	0	0	3	0	0	-5	0	0	5
Tobac	0	0	0	0	0	0	0	0	0
Textl	0	0	-6	1	0	21	3	0	41
Cloth	0	0	0	0	0	0	0	0	0
Leath	0	0	12	0	0	151	0	0	8
Paper	-2	-3	-9	0	0	0	0	0	-1
Chem	-3	-3	-99	13	12	432	8	8	286
Rubber	2	0	95	2	1	132	0	0	10
Nmtmn	-1	0	-8	0	0	-2	4	0	31
Bsmetl	261	19	7,482	644	47	18,459	70	5	2,005
Wdmetl	2	0	53	9	2	243	2	0	63
Nelcmc	0	0	2	5	0	94	2	0	33
Elcmc	2	0	68	-1	0	-22	2	0	76
Trnseq	93	2	1,142	101	2	1,234	8	0	103
Othmn	0	0	3	0	0	1	0	0	6
Total	362	19	8,821	776	65	20,765	130	26	2,960

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Metals to air, water, and land.

Table 4. Effects of NAFTA on Industrial Toxin Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**
Petrol	1,140	80	4,334	277	20	1,055	3,984	280	15,147
Foodpr	14	4	54	122	34	467	15	4	57
Bever	15	2	11	-22	-3	-17	23	3	18
Tobac	26	0	3	-51	0	-5	4	0	0
Textl	-106	-20	-63	349	65	208	682	126	406
Cloth	1	0	1	-1	0	-1	0	0	0
Leath	46	2	89	589	20	1,125	32	1	60
Paper	-1,906	-437	-726	35	8	13	-206	-47	-79
Chem	-967	-287	-2,230	4,217	1,253	9,729	2,793	830	6,443
Rubber	899	2	331	1,247	3	459	99	0	36
Nmtmn	-28	-1	-37	-6	0	-9	110	3	145
Bsmetl	2,867	305	9,479	7,072	752	23,388	768	82	2,540
Wdmetl	364	8	189	1,669	37	867	436	10	227
Nelcmc	6	0	4	348	9	230	124	3	82
Elcmc	284	3	284	-90	-1	-90	315	3	315
Trnseq	15,861	61	6,843	17,149	66	7,399	1,427	5	615
Othmn	31	0	15	15	0	7	62	1	29
Total	18,549	-277	18,581	32,920	2,261	44,826	10,668	1,304	26,044

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Toxins to air, water, and land.

Table 5. Effects of NAFTA on Industrial Water Pollution (thousands of pounds)

	Can	Can	US	US	Mex	Mex
Sector	BOD	TSS	BOD	TSS	BOD	TSS
Petrol	271	1,335	66	325	948	4,664
Foodpr	483	120	4,136	1,032	506	126
Bever	164	297	-245	-441	257	463
Tobac	0	0	0	0	0	0
Textl	0	0	0	0	0	0
Cloth	0	0	0	0	0	0
Leath	8	17	104	216	6	12
Paper	-5,004	-16,838	91	305	-542	-1,823
Chem	-365	-1,224	1,594	5,341	1,056	3,537
Rubber	170	466	236	647	19	51
Nmtmn	-1	-13	0	-3	6	51
Bsmetl	2,245	152,998	5,540	377,481	602	41,003
Wdmetl	18	140	81	642	21	168
Nelcmc	0	1	2	38	1	13
Elcmc	12	17	-4	-5	13	19
Trnseq	14	102	15	110	1	9
Othmn	0	414	0	204	0	825
Total	-1,986	137,832	11,615	385,891	2,893	49,120

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: BOD- biological oxygen demand; and TSS- total suspended solids.

Table 6. 1991 Estimated Base Levels of Industrial Air Pollution (thousands of pounds)

	Can	Can	Can	Can	Can	US	US	US	US	US	Mex	Mex	Mex	Mex	Mex
Sector	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC
Petrol	103,945	333,744	656,969	385,220	289,713	1,111,409	3,568,484	7,024,484	4,118,871	3,097,688	189,263	607,682	1,196,209	701,408	527,510
Foodpr	48,243	14,351	52,634	52,759	13,710	318,667	94,796	347,671	348,493	90,558	129,617	38,558	141,415	141,749	36,834
Bever	1,705	1,377	26,221	16,695	28,342	13,690	11,055	210,503	134,028	227,529	6,066	4,898	93,269	59,385	100,813
Tobac	61	256	3,242	1,962	645	852	3,594	45,596	27,593	9,069	99	418	5,304	3,210	1,055
Textl	1,502	1,321	7,163	9,409	4,307	17,607	15,478	83,951	110,274	50,481	4,399	3,867	20,974	27,550	12,612
Cloth	9	21	202	76	51	85	192	1,825	687	456	8	18	166	62	41
Leath	367	48	666	167	1,159	2,593	341	4,712	1,178	8,193	2,264	298	4,115	1,029	7,154
Paper	53,670	312,633	274,722	151,488	60,222	454,619	2,648,228	2,327,094	1,283,212	510,122	25,978	151,327	132,977	73,326	29,150
Chem.	28,058	252,279	148,870	145,448	122,733	281,119	2,527,650	1,491,567	1,457,283	1,229,692	54,009	485,620	286,564	279,978	236,252
Rubber	1,218	457	10,582	3,635	13,889	14,897	5,591	129,397	44,452	169,833	1,000	375	8,686	2,984	11,401
Nmtmn	34,815	8,746	50,343	39,565	4,661	367,819	92,407	531,874	418,008	49,243	99,717	25,052	144,193	113,324	13,350
Bsmetl	69,283	425,809	555,978	79,558	35,134	477,490	2,934,602	3,831,708	548,297	242,140	57,376	352,625	460,422	65,884	29,096
Wdmetl	44,343	80,697	17,641	34,345	92,287	335,018	609,684	133,284	259,487	697,249	12,615	22,957	5,019	9,771	26,254
Nelcmc	679	4,966	4,592	2,063	5,221	9,763	71,365	65,991	29,643	75,032	702	5,130	4,743	2,131	5,393
Elcmc	1,060	5,410	9,841	4,838	6,585	21,645	110,505	201,019	98,825	134,507	1,150	5,870	10,677	5,249	7,144
Trnseq	4,766	8,115	11,539	5,996	43,092	41,693	70,993	100,952	52,457	376,985	5,081	8,652	12,303	6,393	45,942
Othmn	139	59	269	251	1,534	1,826	780	3,535	3,301	20,164	114	49	221	206	1,260
Total	393,863	1,450,291	1,831,476	933,475	723,283	3,470,792	12,765,745	16,535,164	8,936,091	6,988,943	589,458	1,713,395	2,527,258	1,493,639	1,091,262

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds.

Appendix C

NAFTA and Industrial Pollution:

Some General Equilibrium Results

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*Senior authorship is not assigned. We would like to thank Hugh Arce, Gordon Blaney, Charles Bowman, Antonio Aguilar Bueno, Joseph Flynn, Joseph Francois, Luis Alberto Ibarra, Mark Planting, Erik Poole, Ronald Rioux, Clint Shiells, David Wheeler, and Colleen Williams for data. This has been supported by the Office of the Great Lakes through the Michigan Great Lakes Protection Fund and the Commission for Environmental Cooperation. Contact: Kenneth A. Reinert, School of Public Policy, George Mason University, 3401 North Fairfax Drive, MS 3B1, Arlington, VA 22201, USA, kreinert@gmu.edu.

NAFTA and Industrial Pollution:
Some General Equilibrium Results

Abstract. In recent years, a surge of interest in the linkages between trade and the environment has occurred in the contexts of both regional and multilateral trade agreements. In this paper, we utilize a three-country, applied equilibrium (AGE) model of the North American economy and data from the World Bank's Industrial Pollution Projection System (IPPS) to simulate the industrial pollution impacts of trade liberalization under NAFTA. We find that the most serious environmental consequences of NAFTA occur in the base metals sector. In terms of magnitude, the greatest impacts are in the United States and Canada. The Mexican petroleum sector is also a significant source of industrial pollution, particularly in the case of air pollution. For specific pollutants in specific countries, the transportation equipment sector is also an important source of industrial pollution. This is the case for both volatile organic compounds and toxins released into the air in Canada and the United States. Finally, the chemical sector is a significant source of industrial toxin pollution in the United States and Mexico, but not in Canada.

I. Introduction

In recent years, a surge of interest in the linkages between trade and the environment has occurred in the contexts of both regional trade agreements such the North American Free Trade Area (NAFTA) and multilateral trade agreements such as the Uruguay Round. On the whole, however, the debate over trade and the environment has been more rhetorical than empirical. This is unfortunate because, as has been amply demonstrated [e.g. Runge, 1994, Beghin and Potier, 1997, and Beghin, Roland-Holst, and van der Mensbrugghe, 1997], *a priori* reasoning alone cannot predict whether trade liberalization will have an overall positive or negative impact on the environment. This fact has prompted Beghin, Roland-Holst, and van der Mensbrugghe [1997] to call for "detailed sectoral modeling and estimation" of the linkages between trade and the environment in specific policy contexts.

A few empirical studies do exist. The case of trade and transboundary pollution has been examined by Whalley [1991] and Perronni and Wigle [1994]. Economy-wide models of domestic pollution have been developed by Beghin, Roland-Holst, and van der Mensbrugghe [1995] for the case of Mexico, by Lee and Roland-Holst [1997a,b] in the case of Indonesia and Japan, and by Ferrantino and Linkins [1999] for the case of the Uruguay Round. Examination of these studies provides further testimony to the usefulness of detailed, empirical analysis.

This paper focuses on the industrial pollution impacts of NAFTA. We utilize a three-country, applied equilibrium (AGE) model of the North American economy and make use of the World Bank's Industrial Pollution Projection System (IPPS) to generate results for a detailed set of industrial sectors and pollutants. We simulate the liberalization of tariffs and non-tariff barriers (NTBs) that accompanies NAFTA and provide results for the changes in emissions by industrial sector and pollutant. The results allow us to identify where some of the major environmental impacts of NAFTA are to be found.

We begin in Section II by briefly reviewing the sparse empirical literature on NAFTA and the environment. We then describe in Section III the structure of the AGE model we use to simulate the industrial pollutant effects of NAFTA. We present our simulation results in Section IV and our conclusions in Section V. An appendix describes the construction of the social accounting matrix that comprises the benchmark equilibrium data set of the model.

II. NAFTA and the Environment

As is the case with the general subject of trade and the environment, the literature on NAFTA and the environment is lacking in empirical results. One very notable exception to this is the study by Grossman and Krueger [1993]. These authors combined the output effects of NAFTA as simulated by Brown, Deardorff and Stern [1992] with data from the U.S. Environmental Protection Agency on toxic pollution. With regard to the direct impacts of trade liberalization (as opposed to liberalization-induces increases in investment), these authors found that the greatest increases in toxic pollution occur in the U.S. chemicals sector and the Canadian base metals and rubber and plastics products sectors. Other significant trade-induced increases in toxic pollution occurred in the

Mexican electrical equipment sector, the U.S. paper products sector, and the Canadian transportation equipment sector.

A second notable exception is the study by Beghin, Roland-Holst, and van der Mensbrugghe [1995]. These authors employ a single-country, dynamic AGE model of Mexico. In one simulation scenario, the authors consider "a piecemeal unilateral trade liberalization, along with a modest increase in export prices to mimic terms-of-trade effects that would follow from NAFTA, and increased access to North American markets" (p. 781). The results suggest that trade liberalization contributes to increases in pollution levels, especially in the energy sector. Beghin, Roland-Holst, and van der Mensbrugghe show, however, that these negative pollution impacts can be offset by appropriate abatement policies.

A final empirical study by Abler and Pick [1993] focuses narrowly on the Mexican horticultural sector. Using econometric techniques, these authors conclude that NAFTA contributes to a slight increase in pollution in the Mexican horticultural sector but a slight decrease in pollution in the U.S. horticultural sector. Whether these results can be generalized to the agricultural sector as a whole is not clear.

The present study complements the above studies in providing empirical results for a detailed set of pollutants for all three North American economies. The following section details our modeling approach.

III. AGE Model Structure

The AGE model used to simulate the industrial pollution effects of North American trade liberalization is a three-country, 26-sector model.[1] The trade specification follows that of de Melo and Robinson [1989]. In each sector of each country, domestic demand is constituted of goods which are differentiated by origin (domestic good, imports from each North American trading partner, and imports from the rest of the world). These goods are aggregated using a non-nested, CES functional form into a single consumption good for both intermediate and final use. Also in each sector of each country, domestic production is allocated using a non-nested CET functional form among differentiated

[1] Most AGE modelers have included only one or two of the North American countries in their model. An exception to this is Brown, Deardorff and Stern [1992].

destinations (domestic good, exports to each North American trading partner, and exports to the rest of the world).[2] With regard to each country's relationship to the rest of the world, we maintain the small-country assumption. Exchange rates are flexible, while trade balances are fixed.

Production in each sector of each country utilizes physical capital and labor. These factors are assumed to be perfectly mobile among the sectors of each country but immobile among countries. Production takes place under constant returns to scale using CES functional forms for value added and Leontief intermediates. Final demand in each country is modeled using the LES functional form. All markets are perfectly competitive.

The trade-liberalizing experiments we conduct use observed tariff rates for our base year 1991. In addition, we consider very rough estimates of non-tariff barriers using UNCTAD data on trade control measures. As is general practice [e.g. Gaston and Trefler, 1994], we use NTB coverage ratios as *ad valorem* equivalents. For this reason, our simulations must be interpreted as merely *suggestive* of the impacts of NAFTA on trade, production, and pollution.

The three-country model is calibrated to a 1991 North American social accounting matrix (SAM). The construction of this matrix and its data sources are documented in the appendix. The IPPS effluent data are utilized at the 2- and 3-digit ISIC levels to create *satellite environmental accounts* to this SAM as suggested by Barker [1992], United Nations [1993a,b], and de Haan and Keuning [1996]. As is recommended by their compilers, IPPS effluent data are utilized in their per-employee form. Table 1 describes the IPPS pollutants.[3] In the case of air pollution, the IPPS data include particulates, carbon monoxide, sulfur dioxide, nitrogen dioxide, and volatile organic compounds. In the case of industrial bio-accumulative metals and toxins, the data distinguish among transmission to air, water, and land. Finally, in the case of water

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2 In contrast to the approach taken here, Brown et al. [1992] use a firm-level product differentiation approach. One advantage of the country-level product differentiation approach is that it allows for econometric estimation of trade substitution elasticities. Indeed, we make use of the estimates of Shiells and Reinert [1993] in our calibration of the CES import aggregation functions. That said, we have no quarrel with the firm-level differentiation specification. Both approaches have strengths and weaknesses.

pollution, the data distinguish between biological oxygen demand and total suspended solids. The result is a significant amount of detail in both sectoral and pollutant dimensions which complements the earlier work of Grossman and Krueger [1993].

The calibration of the model also requires a set of behavior parameters. Elasticities of substitution between labor and capital were taken from Reinert and Roland-Holst [1995] for the United States and Mexico and from Delorme and Lester [1990] for Canada. The elasticities of substitution among imports and domestic goods were taken from Shiells and Reinert [1993] for the United States and Canada and from Sobarzo [1992] for Mexico. Elasticities of transformation among exports and domestic supply were taken from Reinert and Roland-Hoslt [1995].

IV. Simulation Results

For the purposes of this paper, we focus a simulation exercise closest to that considered by Brown, Deardorff and Stern [1992] and, therefore, by Grossman and Krueger [1993]. We consider the removal of both tariffs as measured by their observed values and NTBs as measured by coverage ratios. We assume that each North American trading partner maintains its existing protection with respect to the rest of the world. Additionally, as is standard practice in most trade policy models, we assume that total labor supply is fixed in each country. The results of these simulations for each industrial sector and IPPS pollutant are presented in Tables 2 through 5.[4]

Table 2 presents the changes in industrial *air pollution* caused by trade liberalization in North America for each industrial sector of the model. The evidence presented in this table suggests that the industrial air pollution generated as a result of NAFTA will be concentrated in a few particular sectors. These are petroleum, base metals, and transportation equipment. For particulates, carbon monoxide, sulfur dioxide, and nitrogen dioxide, the greatest increases occur in the U.S. base metals sector and in the

[3] On the IPPS, see Hettige, Lucas and Wheeler [1992] and the references therein. See also the web-site listed in our data sources at the end of the paper.
[4] Missing from our analysis is the impact of NAFTA on pollution emissions from the Canadian, U.S., and Mexican agricultural sectors. We refer readers to Abler and Pick [1993] for the case of horticulture in Mexico.

Mexican petroleum sector.[5] In the case of volatile organic compounds, however, the transportation equipment sectors of Canada and the United States are large sources. In terms of total air pollution emissions, the greatest increases are of carbon monoxide and sulfur dioxide in the United States and sulfur dioxide in Mexico. Significant reductions in air pollution occur in the Canadian and Mexican paper sectors and in the Canadian chemicals sector.

Table 3 addresses industrial *bio-accumulative metals pollution.* Here, the petroleum sector plays a less important role than base metals and transportation equipment. The largest emissions are to land, and these occur in the Canadian and U.S. base metals and transportation equipment sectors and in the Mexican base metals sector. In terms of total emissions, the United States leads both Canada and Mexico, primarily as a result of changes in its base metals sector. Again the Canadian chemicals sector registers improvement in emissions, although these are slight.

Table 4 presents the changes in industrial *toxin pollution.* Here, transmission to air is important along with transmission to land. This is especially the case for the transportation equipment sector in Canada. The base metals sector is also important for the transmission of toxins to land in this country.[6] In the United States and Mexico, the chemical sector appears as significant sources of toxins. Importantly, this is *not* the case for Canada where this is a *reduction* of toxin emissions in the chemical sector.[7] As was the case in Tables 2 and 3, this result demonstrates the importance of the general equilibrium analysis of trade and the environment. If reflects the comparative advantage of the U.S. and Mexican chemical sectors over their Canadian counterpart. The U.S. base metals and transportation equipment sectors and the Mexican petroleum sector are also significant sources of toxins, [8] and in terms of total emissions, the U.S. leads with toxic emissions to land and air.

[5] Pollution associated with the petroleum sector in Mexico has been a significant part of the debate over NAFTA and the environment. See Beghin, Roland-Holst, and van der Mensbrugghe [1995] and Commission for Environmental Cooperation [1996].
[6] Qualitatively, these results for Canada agree with those of Grossman and Krueger [1993].
[7] Grossman and Krueger [1993] show a decrease in toxin pollution from the Mexican chemicals sector in their trade-liberalization alone case, but an increase in the trade and investment liberalization case.
[8] Here, our results are in contradiction to those of Grossman and Krueger [1993]. This is most likely due to the different way we model NTBs compared to Brown, Deardorff and Stern [1992].

Finally, Table 5 presents the simulation results for *water pollution.* The base metals sector is again a crucial source of effluents. This is particularly the case for total suspended solids in all three countries. In the case of biological oxygen demand, there is actually an overall decrease in Canada due to the contraction of the paper products sector. The Mexican petroleum sector is a significant source of total suspended solids, but this is an order of magnitude less than in its base metals sector. By far, the greatest concern with regard to water pollution as a result of NAFTA trade liberalization is the increase in total suspended solids from the base metals sector of the United States.

V. Conclusions

The results presented in this paper need to be interpreted with caution. The NTB measures used are in coverage ratio form and thus involve a degree of inaccuracy. Further, the IPPS data are based on conditions in the United States. Although there is evidence that the ranking of pollution intensities is invariant among OECD countries [Hettige, Lucas and Wheeler, 1992], this is obviously not the case with the cardinal values themselves. In our view, the results of Tables 2 through 5 must be considered in ordinal terms as indicating where the most vexing pollution consequences of NAFTA exist. In this sense, the results provide some strong conclusions.[9]

The most serious environmental consequences of NAFTA occur in the base metals sector. In terms of magnitude, the greatest impacts are in the United States and Canada, and this is the case for most of the pollutants considered. As alleged in the debate over NAFTA and the environment, the Mexican petroleum sector is a significant source of industrial pollution, particularly in the case of air pollution. For specific pollutants in specific countries, the transportation equipment sector is also an important source of industrial pollution. This is the case for both volatile organic compounds and toxins released into the air in Canada and the United States. Finally, as suggested by Grossman and Krueger's [1993] results, the chemical sector is a significant source of industrial toxin pollution in the United States and Mexico, but not in Canada. The

[9] It is certainly not the case, as suggested by Kaufman, Pauly, and Sweitzer [1993], that one can say very little about the probable impacts of NAFTA on the environment.

general equilibrium impact of North American trade liberalization result in a *reduction* of toxin pollution in the Canadian chemicals sector.

It is hoped that the results of this paper will contribute to the ongoing discussions of the impacts of NAFTA on the environment and to the work of relevant organizations such as the Montreal-based Commission for Environmental Cooperation (CEC). The results suggest that it may be necessary to develop environmental policies that target specific industrial sources of pollution caused by increased economic integration among the three North American economies.

Appendix: SAM Construction

This appendix provides a brief description of the construction of the 1991 social accounting matrix (SAM) of North America. Construction of the 1991 North American SAM began with the transformation of 1991 national accounts for each country into three separate macroeconomic SAMs. For this purpose, Canadian macroeconomic data were taken from Statistics Canada [1993a and 1993b], U.S. macroeconomic data were taken from U.S. Department of Commerce [1992b], and Mexican macroeconomic data were taken from OECD [1992], Banco de México [1993], Instituto National de Estadística, Geographía e Informática [1992], and International Monetary Fund [1993]. Next, individual macroeconomic SAMs were joined together into a North American macroeconomic SAM using market exchange rates from International Monetary Fund [1993] and aggregate trade flows taken from International Monetary Fund [1992]. Adjustments for maquiladora trade were made with data from Banco de México [1993], and factor service and capital flows were added using data from U.S. Department of Commerce [1992a] and Statistics Canada [1993b].

The next stage of SAM construction involved estimation of the 26 sectoral accounts of each country. Labor value added, property value added, indirect business taxes, value added taxes (for Mexico), domestic final demand, imports, exports, and inter-industry transactions were disaggregated for each country into the 26 sectors. For labor value added, property value added, indirect business taxes, value added taxes, and domestic final demand, this was done using shares from input-output accounts. For Canada, we used 1990 Statistics Canada input output accounts. For the United States, we used 1987 U.S. Department of Labor input-output accounts.[10] In the case of Mexico, we used 1989 SECOFI input output accounts.[11] For imports and exports, the disaggregation was conducted using 10-digit HTS data for the United States and 3-digit SITC data for all three countries. The former were obtained from U.S. Department of Commerce data tapes, and the latter were obtained from United Nations data tapes. Canadian tariffs were estimated from the 1990 input-output data, U.S. tariffs were estimated from the Department of Commerce data, and Mexican tariffs were estimated from data presented in General Agreement on Tariffs and Trade (1993).

For Canada and the United States, 1991 interindustry transactions were estimated using make and use tables for 1990 and 1987, respectively. Make and use tables were balanced using 1991 gross activity output and the RAS procedure.[12] We then removed activity accounts using the Pyatt [1985] procedure. For Mexico, the 1989 transactions matrix was updated to 1991 using 1991 value added, final demand, import and export data.

[10] These are census based. At the time of the work on the SAM, the 1987 U.S. Department of Commerce input-output accounts were not available.
[11] SECOFI is the acronym for Secretaría de Comercio y Fomento Industrial.
[12] On the RAS procedure, see Schneider and Zenios [1990].

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Table 1. The IPPS Pollutants

Name	**Symbol**	**Description**
Particulates	PT	Fine airborne particles that can damage respiratory systems.
Carbon Monoxide	CO	A poisonous gas that inhibits the ability of blood to carry oxygen.
Sulfur Dioxide	SO2	A gas that can contribute to respiratory disease and acid rain.
Nitrogen Dioxide	NO2	A gas that contributes to both respiratory disease and to the formation of acid rain and ozone.
Volatile Organic Compounds	VOC	A class of chemicals associated with skin reactions, nervous system effects, sick-building syndrome, and multiple chemical sensitivity. Many are also suspected carcinogens.
Bio-accumulative Metals	MetAir, MetWat, MetLand	Metals, including mercury, lead, arsenic, chromium, nickel, copper, zinc, and cadmium. They contribute to mental and physical birth defects.
Toxic Pollutants	ToxAir, ToxWat, ToxLand	A class of chemicals that can damage internal organs and neurological functions, cause reproductive problems and birth defects. Many are also suspected carcinogens.
Biological Oxygen Demand	BOD	Organic water pollutants that remove dissolved oxygen. They can damage aquatic species and promote the growth of algae and pathogens.
Total Suspended Solids	TSS	Non-organic, non-toxic particles that can damage aquatic ecosystems and promote the growth of pathogens.

Source: World Bank Industrial Pollution Projection System

Table 2. Industrial Air Pollution (thousands of pounds)

	Can	Can	Can	Can	Can	US	US	US	US	US	Mex	Mex	Mex	Mex	Mex
Sector	**PT**	**CO**	**SO2**	**NO2**	**VOC**	**PT**	**CO**	**SO2**	**NO2**	**VOC**	**PT**	**CO**	**SO2**	**NO2**	**VOC**
petrol	4,384	14,077	27,710	16,248	12,220	1,067	3,426	6,743	3,954	2,974	15,322	49,196	96,840	56,783	42,705
foodpr	325	97	354	355	92	2,782	828	3,035	3,042	791	341	101	372	372	97
bever	25	20	383	244	414	-37	-30	-570	-363	-616	39	31	598	381	646
tobac	2	10	123	74	24	-4	-19	-239	-145	-48	0	2	19	12	4
textl	-55	-48	-261	-343	-157	180	158	857	1,126	515	351	309	1,674	2,199	1,007
cloth	0	0	3	1	1	0	0	-3	-1	-1	0	0	1	0	0
leath	11	1	20	5	35	140	18	254	64	442	8	1	14	3	24
paper	-1,821	-10,609	-9,323	-5,141	-2,044	33	192	169	93	37	-197	-1,149	-1,009	-557	-221
chem	-293	-2,630	-1,552	-1,516	-1,279	1,276	11,472	6,770	6,614	5,581	845	7,598	4,484	4,381	3,696
rubber	99	37	856	294	1,123	137	51	1,188	408	1,559	11	4	94	32	124
nmtmn	-476	-119	-688	-541	-64	-111	-28	-160	-126	-15	1,892	475	2,735	2,150	253
bsmetl	5,016	30,825	40,248	5,759	2,543	12,374	76,052	99,301	14,209	6,275	1,344	8,261	10,786	1,543	682
wdmetl	637	1,159	253	493	1,325	2,920	5,314	1,162	2,261	6,077	763	1,388	304	591	1,588
nelcmc	1	9	9	4	10	71	518	479	215	545	25	184	170	76	193
elcmc	33	168	305	150	204	-10	-53	-96	-47	-64	36	185	337	166	226
trnseq	3,266	5,561	7,908	4,109	29,531	3,531	6,013	8,550	4,443	31,930	294	500	711	370	2,656
othmn	2	1	3	3	18	1	0	2	1	9	3	1	6	6	37
Total	11,156	38,558	66,352	20,199	43,997	24,349	103,913	127,442	35,750	55,991	21,076	67,088	118,136	68,509	53,716

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds.

Table 3. Industrial Bio-accumulative Metals Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	**MetAir**	**MetWat**	**MetLand**	**MetAir**	**MetWat**	**MetLand**	**MetAir**	**MetWat**	**MetLand**
petrol	8	3	84	2	1	20	30	12	292
foodpr	0	0	1	0	0	5	0	0	1
bever	0	0	3	0	0	-5	0	0	5
tobac	0	0	0	0	0	0	0	0	0
textl	0	0	-6	1	0	21	3	0	41
cloth	0	0	0	0	0	0	0	0	0
leath	0	0	12	0	0	151	0	0	8
paper	-2	-3	-9	0	0	0	0	0	-1
chem	-3	-3	-99	13	12	432	8	8	286
rubber	2	0	95	2	1	132	0	0	10
nmtmn	-1	0	-8	0	0	-2	4	0	31
bsmetl	261	19	7,482	644	47	18,459	70	5	2,005
wdmetl	2	0	53	9	2	243	2	0	63
nelcmc	0	0	2	5	0	94	2	0	33
elcmc	2	0	68	-1	0	-22	2	0	76
trnseq	93	2	1,142	101	2	1,234	8	0	103
othmn	0	0	3	0	0	1	0	0	6
Total	362	19	8,821	776	65	20,765	130	26	2,960

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Metals to air, water, and land.

Table 4. Industrial Toxin Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**
Petrol	1,140	80	4,334	277	20	1,055	3,984	280	15,147
Foodpr	14	4	54	122	34	467	15	4	57
Bever	15	2	11	-22	-3	-17	23	3	18
Tobac	26	0	3	-51	0	-5	4	0	0
Textl	-106	-20	-63	349	65	208	682	126	406
Cloth	1	0	1	-1	0	-1	0	0	0
Leath	46	2	89	589	20	1,125	32	1	60
Paper	-1,906	-437	-726	35	8	13	-206	-47	-79
Chem	-967	-287	-2,230	4,217	1,253	9,729	2,793	830	6,443
Rubber	899	2	331	1,247	3	459	99	0	36
Nmtmn	-28	-1	-37	-6	0	-9	110	3	145
Bsmetl	2,867	305	9,479	7,072	752	23,388	768	82	2,540
Wdmetl	364	8	189	1,669	37	867	436	10	227
Nelcmc	6	0	4	348	9	230	124	3	82
Elcmc	284	3	284	-90	-1	-90	315	3	315
Trnseq	15,861	61	6,843	17,149	66	7,399	1,427	5	615
Othmn	31	0	15	15	0	7	62	1	29
Total	18,549	-277	18,581	32,920	2,261	44,826	10,668	1,304	26,044

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Toxins to air, water, and land.

Table 5. Industrial Water Pollution (thousands of pounds)

	Can	Can	US	US	Mex	Mex
Sector	**BOD**	**TSS**	**BOD**	**TSS**	**BOD**	**TSS**
Petrol	271	1,335	66	325	948	4,664
Foodpr	483	120	4,136	1,032	506	126
Bever	164	297	-245	-441	257	463
Tobac	0	0	0	0	0	0
Textl	0	0	0	0	0	0
Cloth	0	0	0	0	0	0
Leath	8	17	104	216	6	12
Paper	-5,004	-16,838	91	305	-542	-1,823
Chem	-365	-1,224	1,594	5,341	1,056	3,537
Rubber	170	466	236	647	19	51
Nmtmn	-1	-13	0	-3	6	51
Bsmetl	2,245	152,998	5,540	377,481	602	41,003
Wdmetl	18	140	81	642	21	168
Nelcmc	0	1	2	38	1	13
Elcmc	12	17	-4	-5	13	19
Trnseq	14	102	15	110	1	9
Othmn	0	414	0	204	0	825
Total	-1,986	137,832	11,615	385,891	2,893	49,120

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: BOD- biological oxygen demand; and TSS- total suspended solids.

Appendix D:

North American Economic Integration and Industrial Pollution in the Great Lakes Region*

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March 2001

To be submitted to *Journal of Policy Analysis and Management.*

* This research has been supported by the Office of the Great Lakes through the Michigan Great Lakes Protection Fund. We would like to thank Jeff Marinucci for Research Assistance and David Roland-Holst for helpful conversations. Contact: Kenneth A. Reinert, School of Public Policy, George Mason University, 3401 North Fairfax Drive, MS 3B1, Arlington, VA 22201, USA, kreinert@gmu.edu.

North American Economic Integration and Industrial Pollution in the Great Lakes Region

Abstract

This paper provides an assessment of the impact of increased economic integration within North America on pollution intensities with the Great Lake states of the United States. We utilize a three-country, applied equilibrium model of the North American economy, data from the World Bank's Industrial Pollution Projection System (IPPS), and employment data from the U.S. Bureau of Economic Analysis to simulate the industrial pollution impacts of North American economic integration within the Great Lakes region. The results reflect the liberalization of tariff and non-tariff barriers, their trade and production impacts, state-level shares in the production changes, and the resulting industrial effluent changes. In many cases, the Great Lake state account for a substantial portion of the total effluent changes caused by North American economic integration.

INTRODUCTION

The policy debates surrounding the negotiation, passage, and assessment of the North American Free Trade Area (NAFTA) have focused to a great extent on the linkages between trade and the environment. By necessity, these debates often take up regional issues. For example, much discussion has focused on the environmental impacts of NAFTA on the U.S.-Mexico border.[1] However, as Nissan (1999) has shown, the Great Lake States of the United States have closer ties with Canada. Indeed, pollution concerns in the Great Lakes region are evident in the numerous pollution initiatives occurring on both sides of the U.S.-Canadian border. These include, but are not limited to, the Great Lakes Regional Pollution Prevention Roundtable, the Great Lakes Information Network, the Great Lakes Pollution Prevention Initiative, and the Binational Toxins Strategy.[2] In the case of industrial pollutions, the Great Lake states are particularly important since these comprise approximately one third of U.S. manufacturing output.[3]

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[1] For a definitive review, including the border issues, see Johnson and Beaulieu (1996).
[2] See also Dworsky (1993) and Valiante, Muldoon, and Botts (1997).
[3] See Allardice and Thorp (1995).

This paper provides an assessment of the impact of increased economic integration within North America on industrial pollution intensities with the Great Lake states of the United States. We utilize a three-country, applied equilibrium (AGE) model of the North American economy, data from the World Bank's Industrial Pollution Projection System (IPPS), as well as employment data from the U.S. Bureau of Economic Analysis (BEA) simulate the industrial pollution impacts of North American economic integration within the Great Lakes region. The results reflect the liberalization of tariff and non-tariff barriers, their trade and production impacts, state-level shares in the production changes, and the resulting industrial effluent changes.

MODELING APPROACH

Our starting point is the Applied General Equilibrium (AGE) model of the North American economy developed by Reinert and Roland-Holst (1998) for the year 1991. Importantly, this is a full, three-country model, incorporating production, consumption and trade relationships in Canada, the United States, and Mexico. The AGE model is described in some detail in the appendix to this paper.[4] The trade-liberalizing experiment we choose use observed tariff rates for our base year 1991. In addition, it uses very rough estimates of non-tariff barriers using UNCTAD data on trade control measures. As is general practice (e.g. Gaston and Trefler, 1994), we use NTB coverage ratios as *ad valorem* equivalents.[5]

We use the IPPS effluent data at the 3-digit level. These data have been aggregated to our sectoring scheme for each of the three countries individually using data from the United Nations Industrial Development Organization (UNIDO). As is recommended by their compilers, IPPS effluent data are utilized in their per-employee form. Table 1 describes the IPPS pollutants.[6] In the case of air pollution, the IPPS data include particulates, carbon monoxide, sulfur dioxide, nitrogen dioxide, and volatile organic compounds. In the case of industrial bio-accumulative metals and toxins, the data

[4] Readers not familiar with this style of economic modeling can consult Devarajan et al. (1997). A different modeling approach to the Great Lakes can be found in Lichty, McDonald, and Lampher (1996).
[5] The NTB measures are detailed in Roland-Holst, Reinert, and Shiells (1994).
[6] On the IPPS, see Hettige, Lucas and Wheeler (1992) and the references therein.

distinguish among transmission to air, water, and land. Finally, in the case of water pollution, the data distinguish between biological oxygen demand and total suspended solids. The result is a significant amount of detail in both sectoral and pollutant dimensions.

In order to estimate the impacts of North American economic integration on industrial pollution within the Great Lakes states, we utilize state-level employment data for 1991 from the U.S. Bureau of Economic Analysis. We utilize employment shares by industry for Illinois, Indiana, Ohio, Michigan, Minnesota, New York, Pennsylvania, and Wisconsin.

SIMULATIONS

A great deal of results is generated in an exercise such as the one we have conducted. In order to make these results presentable, we consider each pollutant type and aggregate the results over the Great Lakes states.[7] The pollutant types we consider are air pollution, bio-accumulative metals pollution, industrial toxin pollution, and water pollution.

Table 2 presents the changes in industrial *air pollution* in the Great Lake states caused by trade liberalization in North America for each industrial sector of the Reinert/Roland-Holst model. In the case of particulates, the two most important contributors are the base metal and transportation equipment sectors.[8] This is also the case for sulfur dioxide and volatile organic compounds. For carbon monoxide and nitrogen dioxide, the two most important contributors are the base metal and chemical sectors. The petroleum sector is also of note as a significant source of some air pollutants. In case of sulfur dioxide, the Great Lake states account for just short of one half of the additional U.S. emissions cause by North American economic integration.

Table 3 presents the changes in industrial *bio-accumulative metals pollution* in the Great Lake states caused by trade liberalization in North America for each industrial sector of the Reinert/Roland-Holst model. For all three pollution types (metals to air, metals to water, and metals to land), the base metals sector is the most important source of emissions. For the case of metals to land, the chemicals, wood and metal products and

[7] Country-level results can be found in Reinert and Roland-Holst (2001a).
[8] With regard to base metals, the Great Lakes states account for approximately 70 percent of total U.S. steel production. See Allardice and Thorp (1995).

transportation equipment sectors are also significant sources. For all three pollution types, the Great Lake states account for approximately one half of the additional U.S. emissions caused by North American economic integration.

Table 4 presents the changes in industrial *toxin pollution* in the Great Lake states caused by trade liberalization in North America for each industrial sector of the Reinert/Roland-Holst model. Except for the case of toxins to water, where the transportation equipment sector is not important, the chemicals, base metals, and transportation equipment sectors are the most significant sources of toxin pollution accumulating to air, water, and land. For toxin pollution, the Great Lake states are less important in contributing to U.S. totals than for air and bio-accumulative metals.

Table 5 presents the changes in industrial *water pollution* in the Great Lake states caused by trade liberalization in North America for each industrial sector of the Reinert/Roland-Holst model.[9] Once again, the base metals sector appears as a significant source of emissions. In the case of biological oxygen demand, the food processing sector is also a significant source of emissions, and in the case of total suspended solids, so does the chemicals sector. The case of total suspended solids is very notable here in that the Great Lake states contribute approximately 60 percent of the U.S. total. This type of water pollution would appear to be of major concern to the Great Lakes ecosystem.

Finally, Tables 6 through 9 provide results equivalent to Tables 2 through 5 for the state of Michigan. For comparison purposes, the Great Lakes totals from Tables 2 through 5 are listed at the bottom of each of these Michigan tables.

CONCLUSIONS

The Great Lakes are positioned on the border of two countries in the process of increased economic integration. Given the fragile nature of these water resources, there has been a great deal of concern about the linkage in the Great Lakes region between increased economic activity and environmental degradation. In the case of industrial pollutions, the

[9] "The Great Lakes region's abundant water supply is an important resource connection for industry. Water use in manufacturing operations is concentrated in five major sectors: steel production, food processing, petroleum refining, chemicals/allied products and paper—all of which are well-represented in the regional economy. This intensity of water use is illustrated by the fact that the Great Lakes states account for 40% of U.S. industrial water use, and much of this demand is based in the Basin" (Allardice and Thorp, 1995).

Great Lake states are particularly important since these comprise approximately one third of U.S. manufacturing output. Indeed, as demonstrated by the results presented in Tables 2 through 5, the Great Lake states account for a substantial portion of the total industrial pollution generated by increased integration of the North American economies. These effects are concentrated in the chemical, base metal, wood and metal product, and transportation equipment sectors. For specific pollutants, the petroleum and food processing sectors are also important sources.

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APPENDIX: AGE MODEL STRUCTURE

The AGE model used to simulate the industrial pollution effects of North American trade liberalization is a three-country, 26-sector model calibrated to a 1991 social accounting matrix. The construction of this social accounting matrix is described in Reinert and Roland-Holst (2001b). The trade specification follows that of de Melo and Robinson (1989). In each sector of each country, domestic demand is constituted of goods that are differentiated by origin (domestic good, imports from each North American trading partner, and imports from the rest of the world) and destination (domestic good, exports to each North American trading partner, and exports to the rest of the world). With regard to each country's relationship to the rest of the world, we maintain the small-country assumption of fixed world prices. Exchange rates are flexible, while trade balances are fixed.

Production in each sector of each country utilizes physical capital and labor. These factors are assumed to be perfectly mobile among the sectors of each country but immobile among countries. Production takes place under constant returns to scale using constant elasticity of substitution (CES) functional forms for value added and Leontief (fixed coefficient) intermediates. Final demand in each country is modeled using the linear expenditure (LES) functional form. All markets are perfectly competitive.

The calibration of the model also requires a set of behavior parameters. These include elasticities of substitution between labor and capital, elasticities of substitution among imports and domestic goods, and elasticities of transformation among exports and domestic supply. Sources for these elasticities can be found in Reinert and Roland-Holst (2001a).

Table 1. The IPPS Pollutants

Name	Symbol	Description
Particulates	PT	Fine airborne particles that can damage respiratory systems.
Carbon Monoxide	CO	A poisonous gas that inhibits the ability of blood to carry oxygen.
Sulfur Dioxide	SO2	A gas that can contribute to respiratory disease and acid rain.
Nitrogen Dioxide	NO2	A gas that contributes to both respiratory disease and to the formation of acid rain and ozone.
Volatile Organic Compounds	VOC	A class of chemicals associated with skin reactions, nervous system effects, sick-building syndrome, and multiple chemical sensitivity. Many are also suspected carcinogens.
Bio-accumulative Metals	MetAir, MetWat, MetLand	Metals, including mercury, lead, arsenic, chromium, nickel, copper, zinc, and cadmium. They contribute to mental and physical birth defects.
Toxic Pollutants	ToxAir, ToxWat, ToxLand	A class of chemicals that can damage internal organs and neurological functions, cause reproductive problems and birth defects. Many are also suspected carcinogens.
Biological Oxygen Demand	BOD	Organic water pollutants that remove dissolved oxygen. They can damage aquatic species and promote the growth of algae and pathogens.
Total Suspended Solids	TSS	Non-organic, non-toxic particles that can damage aquatic ecosystems and promote the growth of pathogens.

Source: World Bank Industrial Pollution Projection System

Table 2. North American Integration and Industrial Air Pollution in the Great Lake States (thousands of pounds)

Sector	**PT**	**CO**	**SO2**	**NO2**	**VOC**
petrol	279	1,104	2,153	1,252	1,027
foodpr	681	214	1,008	905	451
textl	14	13	68	89	41
cloth	0	0	-1	0	0
leath	38	5	70	17	124
paper	7	42	37	20	10
chem.	400	3,919	2,068	1,975	1,700
rubber	29	10	235	79	436
nmtmn	-71	-13	-98	-65	-5
bsmetl	6,682	41,965	47,883	8,797	3,498
wdmetl	719	1,591	322	699	1,748
nelcmc	31	226	209	94	238
elcmc	-3	-18	-32	-16	-21
trnseq	1,279	2,177	3,096	1,609	11,563
othmn	0	0	0	0	2
great lakes total	10,086	51,236	57,018	15,458	20,811
us total	24,349	103,913	127,442	35,750	55,991

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds.

Table 3.North American Integration and Industrial Bio-accumulative Metals Pollution in the Great Lakes States (thousands of pounds)

Sector	MetAir	MetWat	MetLand
petrol	1	0	7
foodpr	0	0	3
textl	0	0	2
cloth	0	0	0
leath	0	0	41
paper	0	0	0
chem.	4	4	128
rubber	1	0	28
nmtmn	0	0	0
bsmetl	330	29	9,053
wdmetl	5	1	143
nelcmc	2	0	41
elcmc	0	0	-7
trnseq	37	1	447
othmn	0	0	0
great lakes total	379	35	9,887
us total	776	65	20,765

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Metals to air, water, and land.

Table 4. North American Integration and Industrial Toxin Pollution in the Great Lakes States (thousands of pounds)

Sector	ToxAir	ToxWat	ToxLand
petrol	95	7	378
foodpr	49	10	120
textl	28	5	17
cloth	0	0	0
leath	171	6	308
paper	9	2	3
chem.	1,284	370	2,911
rubber	637	2	206
nmtmn	-3	0	-4
bsmetl	3,303	443	11,816
wdmetl	635	22	491
nelcmc	152	4	101
elcmc	-30	0	-30
trnseq	6,210	24	2,679
othmn	5	0	2
great lakes total	12,544	893	18,998
us total	32,920	2,261	44,826

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Toxins to air, water, and land.

Table 5. North American Integration and Industrial Water Pollution in the Great Lakes States (thousands of pounds)

Sector	BOD	TSS
petrol	23	116
foodpr	1,089	427
textl	3	4
cloth	0	0
leath	30	61
paper	20	67
chem.	470	1,734
rubber	154	124
nmtmn	0	-2
bsmetl	2,304	229,424
wdmetl	24	274
nelcmc	1	17
elcmc	-1	-2
trnseq	5	40
othmn	0	40
great lakes total	4,122	232,325
us total	11,615	385,891

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: BOD- biological oxygen demand; and TSS- total suspended solids.

Table 6. North American Integration and Industrial Air Pollution in Michigan (thousands of pounds)

Sector	PT	CO	SO2	NO2	VOC
petrol	15	58	113	66	54
foodpr	59	19	88	79	39
textl	0	0	0	0	0
cloth	0	0	0	0	0
leath	3	0	5	1	9
paper	1	3	3	2	1
chem.	51	503	265	253	218
rubber	4	1	33	11	60
nmtmn	-7	-1	-9	-6	0
bsmetl	656	4,119	4,700	863	343
wdmetl	124	275	56	121	302
nelcmc	4	31	29	13	32
elcmc	0	-1	-2	-1	-1
trnseq	518	882	1,255	652	4,686
othmn	0	0	0	0	0
michigan total	1,428	5,889	6,535	2,054	5,744
great lakes total	10,086	51,236	57,018	15,458	20,811

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds.

Table 7.North American Integration and Industrial Bio-accumulative Metals Pollution in Michigan (thousands of pounds)

Sector	MetAir	MetWat	MetLand
petrol	0	0	0
foodpr	0	0	0
textl	0	0	0
cloth	0	0	0
leath	0	0	3
paper	0	0	0
chem.	0	0	16
rubber	0	0	4
nmtmn	0	0	0
bsmetl	32	3	889
wdmetl	1	0	25
nelcmc	0	0	6
elcmc	0	0	0
trnseq	15	0	181
othmn	0	0	0
michigan total	49	4	1,124
great lakes total	379	35	9,887

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Metals to air, water, and land.

Table 8. North American Integration and Industrial Toxin Pollution in Michigan (thousands of pounds)

Sector	**ToxAir**	**ToxWat**	**ToxLand**
petrol	5	0	20
foodpr	4	1	10
textl	0	0	0
cloth	0	0	0
leath	12	0	22
paper	1	0	0
chem.	165	47	373
rubber	88	0	28
nmtmn	0	0	0
bsmetl	324	43	1,160
wdmetl	110	4	85
nelcmc	21	1	14
elcmc	-2	0	-2
trnseq	2,517	10	1,086
othmn	0	0	0
michigan total	3,245	107	2,797
great lakes total	12,544	893	18,998

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Toxins to air, water, and land.

Table 9. North American Integration and Industrial Water Pollution in Michigan (thousands of pounds)

Sector	BOD	TSS
petrol	1	6
foodpr	95	37
textl	0	0
cloth	0	0
leath	2	4
paper	2	5
chem.	60	222
rubber	21	17
nmtmn	0	0
bsmetl	226	22,518
wdmetl	4	47
nelcmc	0	2
elcmc	0	0
trnseq	2	16
othmn	0	2
michigan total	414	22,878
great lakes total	4,122	232,325

Sectors are: petroleum; food processing;; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: BOD- biological oxygen demand; and TSS- total suspended solids.

Table 2. Effects of NAFTA on Industrial Air Pollution (thousands of pounds)

	Can	Can	Can	Can	Can	US	US	US	US	US	Mex	Mex	Mex	Mex	Mex
Sector	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC
Petrol	4,384	14,077	27,710	16,248	12,220	1,067	3,426	6,743	3,954	2,974	15,322	49,196	96,840	56,783	42,705
Foodpr	325	97	354	355	92	2,782	828	3,035	3,042	791	341	101	372	372	97
Bever	25	20	383	244	414	-37	-30	-570	-363	-616	39	31	598	381	646
Tobac	2	10	123	74	24	-4	-19	-239	-145	-48	0	2	19	12	4
Textl	-55	-48	-261	-343	-157	180	158	857	1,126	515	351	309	1,674	2,199	1,007
Cloth	0	0	3	1	1	0	0	-3	-1	-1	0	0	1	0	0
Leath	11	1	20	5	35	140	18	254	64	442	8	1	14	3	24
Paper	-1,821	-10,609	-9,323	-5,141	-2,044	33	192	169	93	37	-197	-1,149	-1,009	-557	-221
Chem.	-293	-2,630	-1,552	-1,516	-1,279	1,276	11,472	6,770	6,614	5,581	845	7,598	4,484	4,381	3,696
Rubber	99	37	856	294	1,123	137	51	1,188	408	1,559	11	4	94	32	124
Nmtmn	-476	-119	-688	-541	-64	-111	-28	-160	-126	-15	1,892	475	2,735	2,150	253
Bsmetl	5,016	30,825	40,248	5,759	2,543	12,374	76,052	99,301	14,209	6,275	1,344	8,261	10,786	1,543	682
Wdmetl	637	1,159	253	493	1,325	2,920	5,314	1,162	2,261	6,077	763	1,388	304	591	1,588
Nelcmc	1	9	9	4	10	71	518	479	215	545	25	184	170	76	193
Elcmc	33	168	305	150	204	-10	-53	-96	-47	-64	36	185	337	166	226
Trnseq	3,266	5,561	7,908	4,109	29,531	3,531	6,013	8,550	4,443	31,930	294	500	711	370	2,656
Othmn	2	1	3	3	18	1	0	2	1	9	3	1	6	6	37
Total	11,156	38,558	66,352	20,199	43,997	24,349	103,913	127,442	35,750	55,991	21,076	67,088	118,136	68,509	53,716

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds.

Table 3. Effects of NAFTA on Industrial Bio-accumulative Metals Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	**MetAir**	**MetWat**	**MetLand**	**MetAir**	**MetWat**	**MetLand**	**MetAir**	**MetWat**	**MetLand**
Petrol	8	3	84	2	1	20	30	12	292
Foodpr	0	0	1	0	0	5	0	0	1
Bever	0	0	3	0	0	-5	0	0	5
Tobac	0	0	0	0	0	0	0	0	0
Textl	0	0	-6	1	0	21	3	0	41
Cloth	0	0	0	0	0	0	0	0	0
Leath	0	0	12	0	0	151	0	0	8
Paper	-2	-3	-9	0	0	0	0	0	-1
Chem	-3	-3	-99	13	12	432	8	8	286
Rubber	2	0	95	2	1	132	0	0	10
Nmtmn	-1	0	-8	0	0	-2	4	0	31
Bsmetl	261	19	7,482	644	47	18,459	70	5	2,005
Wdmetl	2	0	53	9	2	243	2	0	63
Nelcmc	0	0	2	5	0	94	2	0	33
Elcmc	2	0	68	-1	0	-22	2	0	76
Trnseq	93	2	1,142	101	2	1,234	8	0	103
Othmn	0	0	3	0	0	1	0	0	6
Total	362	19	8,821	776	65	20,765	130	26	2,960

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures. Pollutants are: Metals to air, water, and land.

Table 4. Effects of NAFTA on Industrial Toxin Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**
Petrol	1,140	80	4,334	277	20	1,055	3,984	280	15,147
Foodpr	14	4	54	122	34	467	15	4	57
Bever	15	2	11	-22	-3	-17	23	3	18
Tobac	26	0	3	-51	0	-5	4	0	0
Textl	-106	-20	-63	349	65	208	682	126	406
Cloth	1	0	1	-1	0	-1	0	0	0
Leath	46	2	89	589	20	1,125	32	1	60
Paper	-1,906	-437	-726	35	8	13	-206	-47	-79
Chem	-967	-287	-2,230	4,217	1,253	9,729	2,793	830	6,443
Rubber	899	2	331	1,247	3	459	99	0	36
Nmtmn	-28	-1	-37	-6	0	-9	110	3	145
Bsmetl	2,867	305	9,479	7,072	752	23,388	768	82	2,540
Wdmetl	364	8	189	1,669	37	867	436	10	227
Nelcmc	6	0	4	348	9	230	124	3	82
Elcmc	284	3	284	-90	-1	-90	315	3	315
Trnseq	15,861	61	6,843	17,149	66	7,399	1,427	5	615
Othmn	31	0	15	15	0	7	62	1	29
Total	18,549	-277	18,581	32,920	2,261	44,826	10,668	1,304	26,044

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Toxins to air, water, and land.

Table 5. Effects of NAFTA on Industrial Water Pollution (thousands of pounds)

	Can	Can	US	US	Mex	Mex
Sector	BOD	TSS	BOD	TSS	BOD	TSS
Petrol	271	1,335	66	325	948	4,664
Foodpr	483	120	4,136	1,032	506	126
Bever	164	297	-245	-441	257	463
Tobac	0	0	0	0	0	0
Textl	0	0	0	0	0	0
Cloth	0	0	0	0	0	0
Leath	8	17	104	216	6	12
Paper	-5,004	-16,838	91	305	-542	-1,823
Chem	-365	-1,224	1,594	5,341	1,056	3,537
Rubber	170	466	236	647	19	51
Nmtmn	-1	-13	0	-3	6	51
Bsmetl	2,245	152,998	5,540	377,481	602	41,003
Wdmetl	18	140	81	642	21	168
Nelcmc	0	1	2	38	1	13
Elcmc	12	17	-4	-5	13	19
Trnseq	14	102	15	110	1	9
Othmn	0	414	0	204	0	825
Total	-1,986	137,832	11,615	385,891	2,893	49,120

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: BOD- biological oxygen demand; and TSS- total suspended solids.

Table 6. 1991 Estimated Base Levels of Industrial Air Pollution (thousands of pounds)

	Can	Can	Can	Can	Can	US	US	US	US	US	Mex	Mex	Mex	Mex	Mex
Sector	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC	PT	CO	SO2	NO2	VOC
Petrol	103,945	333,744	656,969	385,220	289,713	1,111,409	3,568,484	7,024,484	4,118,871	3,097,688	189,263	607,682	1,196,209	701,408	527,510
Foodpr	48,243	14,351	52,634	52,759	13,710	318,667	94,796	347,671	348,493	90,558	129,617	38,558	141,415	141,749	36,834
Bever	1,705	1,377	26,221	16,695	28,342	13,690	11,055	210,503	134,028	227,529	6,066	4,898	93,269	59,385	100,813
Tobac	61	256	3,242	1,962	645	852	3,594	45,596	27,593	9,069	99	418	5,304	3,210	1,055
Textl	1,502	1,321	7,163	9,409	4,307	17,607	15,478	83,951	110,274	50,481	4,399	3,867	20,974	27,550	12,612
Cloth	9	21	202	76	51	85	192	1,825	687	456	8	18	166	62	41
Leath	367	48	666	167	1,159	2,593	341	4,712	1,178	8,193	2,264	298	4,115	1,029	7,154
Paper	53,670	312,633	274,722	151,488	60,222	454,619	2,648,228	2,327,094	1,283,212	510,122	25,978	151,327	132,977	73,326	29,150
Chem.	28,058	252,279	148,870	145,448	122,733	281,119	2,527,650	1,491,567	1,457,283	1,229,692	54,009	485,620	286,564	279,978	236,252
Rubber	1,218	457	10,582	3,635	13,889	14,897	5,591	129,397	44,452	169,833	1,000	375	8,686	2,984	11,401
Nmtmn	34,815	8,746	50,343	39,565	4,661	367,819	92,407	531,874	418,008	49,243	99,717	25,052	144,193	113,324	13,350
Bsmetl	69,283	425,809	555,978	79,558	35,134	477,490	2,934,602	3,831,708	548,297	242,140	57,376	352,625	460,422	65,884	29,096
Wdmetl	44,343	80,697	17,641	34,345	92,287	335,018	609,684	133,284	259,487	697,249	12,615	22,957	5,019	9,771	26,254
Nelcmc	679	4,966	4,592	2,063	5,221	9,763	71,365	65,991	29,643	75,032	702	5,130	4,743	2,131	5,393
Elcmc	1,060	5,410	9,841	4,838	6,585	21,645	110,505	201,019	98,825	134,507	1,150	5,870	10,677	5,249	7,144
Trnseq	4,766	8,115	11,539	5,996	43,092	41,693	70,993	100,952	52,457	376,985	5,081	8,652	12,303	6,393	45,942
Othmn	139	59	269	251	1,534	1,826	780	3,535	3,301	20,164	114	49	221	206	1,260
Total	393,863	1,450,291	1,831,476	933,475	723,283	3,470,792	12,765,745	16,535,164	8,936,091	6,988,943	589,458	1,713,395	2,527,258	1,493,639	1,091,262

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: PT- particulates; CO- carbon monoxide; SO2- sulfur dioxide; NO2- nitrogen dioxide; VOC- volatile organic compounds.

Table 7. 1991 Estimated Base Levels of Industrial Bio-accumulative Metals Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	MetAir	MetWat	MetLand	MetAir	MetWat	MetLand	MetAir	MetWat	MetLand
Petrol	201	79	1,983	2,152	850	21,207	366	145	3,611
Foodpr	1	6	84	4	40	554	2	16	225
Bever	1	0	221	5	1	1,771	2	0	785
Tobac	0	0	0	0	0	0	0	0	0
Textl	11	1	175	129	7	2,056	32	2	514
Cloth	0	0	5	1	0	49	0	0	4
Leath	1	0	397	4	3	2,804	3	2	2,449
Paper	65	86	278	554	727	2,351	32	42	134
Chem	278	266	9,491	2,781	2,662	95,089	534	511	18,269
Rubber	22	5	1,176	271	62	14,385	18	4	966
Nmtmn	71	1	577	747	11	6,098	202	3	1,653
Bsmetl	3,604	262	103,352	24,836	1,804	712,286	2,984	217	85,589
Wdmetl	137	27	3,683	1,032	206	27,829	39	8	1,048
Nelcmc	46	1	903	664	17	12,980	48	1	933
Elcmc	70	6	2,206	1,420	121	45,069	75	6	2,394
Trnseq	136	3	1,666	1,190	23	14,573	145	3	1,776
Othmn	16	1	242	207	13	3,179	13	1	199
Total	4,658	744	126,440	35,998	6,547	962,280	4,497	961	120,549

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Metals to air, water, and land.

Table 8. 1991 Estimated Base Levels of Industrial Toxin Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**
Petrol	27,031	1,901	102,761	289,020	20,329	1,098,744	49,218	3,462	187,107
Foodpr	2,110	594	8,098	13,936	3,925	53,489	5,669	1,597	21,757
Bever	1,010	150	785	8,108	1,201	6,305	3,592	532	2,794
Tobac	696	5	69	9,795	67	971	1,139	8	113
Textl	2,918	540	1,736	34,198	6,326	20,349	8,544	1,580	5,084
Cloth	81	0	31	735	0	277	67	0	25
Leath	1,545	53	2,950	10,929	376	20,864	9,543	329	18,219
Paper	56,159	12,865	21,405	475,704	108,972	181,315	27,183	6,227	10,361
Chem	92,731	27,548	213,945	929,097	276,014	2,143,566	178,501	53,029	411,828
Rubber	11,116	27	4,093	135,926	334	50,043	9,124	22	3,359
Nmtmn	2,031	57	2,676	21,452	603	28,274	5,816	164	7,665
Bsmetl	39,598	4,208	130,946	272,904	28,998	902,456	32,792	3,484	108,440
Wdmetl	25,354	557	13,168	191,559	4,212	99,484	7,213	159	3,746
Nelcmc	3,335	83	2,207	47,929	1,196	31,719	3,445	86	2,280
Elcmc	9,181	95	9,181	187,540	1,946	187,540	9,961	103	9,961
Trnseq	23,144	89	9,986	202,476	778	87,358	24,675	95	10,646
Othmn	2,609	22	1,214	34,303	285	15,959	2,144	18	997
Total	300,650	48,794	525,250	2,865,609	455,563	4,928,712	378,627	70,894	804,383

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures. Pollutants are: Toxins to air, water, and land.

Table 9. 1991 Estimated Base Levels of Industrial Water Pollution (thousands of pounds)

	Can	Can	US	US	Mex	Mex
Sector	BOD	TSS	BOD	TSS	BOD	TSS
Petrol	6,429	31,644	68,740	338,343	11,706	57,617
Foodpr	71,723	17,901	473,763	118,243	192,703	48,095
Bever	11,260	20,306	90,393	163,019	40,051	72,230
Tobac	4	5	55	67	6	8
Textl	0	0	0	0	0	0
Cloth	0	0	0	0	0	0
Leath	272	566	1,923	4,001	1,680	3,494
Paper	147,473	496,180	1,249,198	4,202,995	71,383	240,171
Chem	35,046	117,452	351,139	1,176,778	67,462	226,086
Rubber	2,103	5,763	25,715	70,471	1,726	4,731
Nmtmn	105	944	1,112	9,969	302	2,703
Bsmetl	31,016	2,113,480	213,755	14,565,745	25,685	1,750,237
Wdmetl	1,235	9,753	9,330	73,684	351	2,774
Nelcmc	17	364	244	5,232	18	376
Elcmc	382	545	7,812	11,131	415	591
Trnseq	20	149	175	1,302	21	159
Othmn	3	34,463	36	453,135	2	28,322
Total	307,088	2,849,513	2,493,391	21,194,116	413,510	2,437,594

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: BOD- biological oxygen demand; and TSS- total suspended solids.

Appendix C

NAFTA and Industrial Pollution:

Some General Equilibrium Results

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Forthcoming, *Journal of Economic Integration*, 2001.

*Senior authorship is not assigned. We would like to thank Hugh Arce, Gordon Blaney, Charles Bowman, Antonio Aguilar Bueno, Joseph Flynn, Joseph Francois, Luis Alberto Ibarra, Mark Planting, Erik Poole, Ronald Rioux, Clint Shiells, David Wheeler, and Colleen Williams for data. This has been supported by the Office of the Great Lakes through the Michigan Great Lakes Protection Fund and the Commission for Environmental Cooperation. Contact: Kenneth A. Reinert, School of Public Policy, George Mason University, 3401 North Fairfax Drive, MS 3B1, Arlington, VA 22201, USA, kreinert@gmu.edu.

Table 7. 1991 Estimated Base Levels of Industrial Bio-accumulative Metals Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	MetAir	MetWat	MetLand	MetAir	MetWat	MetLand	MetAir	MetWat	MetLand
Petrol	201	79	1,983	2,152	850	21,207	366	145	3,611
Foodpr	1	6	84	4	40	554	2	16	225
Bever	1	0	221	5	1	1,771	2	0	785
Tobac	0	0	0	0	0	0	0	0	0
Textl	11	1	175	129	7	2,056	32	2	514
Cloth	0	0	5	1	0	49	0	0	4
Leath	1	0	397	4	3	2,804	3	2	2,449
Paper	65	86	278	554	727	2,351	32	42	134
Chem	278	266	9,491	2,781	2,662	95,089	534	511	18,269
Rubber	22	5	1,176	271	62	14,385	18	4	966
Nmtmn	71	1	577	747	11	6,098	202	3	1,653
Bsmetl	3,604	262	103,352	24,836	1,804	712,286	2,984	217	85,589
Wdmetl	137	27	3,683	1,032	206	27,829	39	8	1,048
Nelcmc	46	1	903	664	17	12,980	48	1	933
Elcmc	70	6	2,206	1,420	121	45,069	75	6	2,394
Trnseq	136	3	1,666	1,190	23	14,573	145	3	1,776
Othmn	16	1	242	207	13	3,179	13	1	199
Total	4,658	744	126,440	35,998	6,547	962,280	4,497	961	120,549

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures. Pollutants are: Metals to air, water, and land.

Table 8. 1991 Estimated Base Levels of Industrial Toxin Pollution (thousands of pounds)

	Can	Can	Can	US	US	US	Mex	Mex	Mex
Sector	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**	**ToxAir**	**ToxWat**	**ToxLand**
Petrol	27,031	1,901	102,761	289,020	20,329	1,098,744	49,218	3,462	187,107
Foodpr	2,110	594	8,098	13,936	3,925	53,489	5,669	1,597	21,757
Bever	1,010	150	785	8,108	1,201	6,305	3,592	532	2,794
Tobac	696	5	69	9,795	67	971	1,139	8	113
Textl	2,918	540	1,736	34,198	6,326	20,349	8,544	1,580	5,084
Cloth	81	0	31	735	0	277	67	0	25
Leath	1,545	53	2,950	10,929	376	20,864	9,543	329	18,219
Paper	56,159	12,865	21,405	475,704	108,972	181,315	27,183	6,227	10,361
Chem	92,731	27,548	213,945	929,097	276,014	2,143,566	178,501	53,029	411,828
Rubber	11,116	27	4,093	135,926	334	50,043	9,124	22	3,359
Nmtmn	2,031	57	2,676	21,452	603	28,274	5,816	164	7,665
Bsmetl	39,598	4,208	130,946	272,904	28,998	902,456	32,792	3,484	108,440
Wdmetl	25,354	557	13,168	191,559	4,212	99,484	7,213	159	3,746
Nelcmc	3,335	83	2,207	47,929	1,196	31,719	3,445	86	2,280
Elcmc	9,181	95	9,181	187,540	1,946	187,540	9,961	103	9,961
Trnseq	23,144	89	9,986	202,476	778	87,358	24,675	95	10,646
Othmn	2,609	22	1,214	34,303	285	15,959	2,144	18	997
Total	300,650	48,794	525,250	2,865,609	455,563	4,928,712	378,627	70,894	804,383

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: Toxins to air, water, and land.

Table 9. 1991 Estimated Base Levels of Industrial Water Pollution (thousands of pounds)

	Can	Can	US	US	Mex	Mex
Sector	BOD	TSS	BOD	TSS	BOD	TSS
Petrol	6,429	31,644	68,740	338,343	11,706	57,617
Foodpr	71,723	17,901	473,763	118,243	192,703	48,095
Bever	11,260	20,306	90,393	163,019	40,051	72,230
Tobac	4	5	55	67	6	8
Textl	0	0	0	0	0	0
Cloth	0	0	0	0	0	0
Leath	272	566	1,923	4,001	1,680	3,494
Paper	147,473	496,180	1,249,198	4,202,995	71,383	240,171
Chem	35,046	117,452	351,139	1,176,778	67,462	226,086
Rubber	2,103	5,763	25,715	70,471	1,726	4,731
Nmtmn	105	944	1,112	9,969	302	2,703
Bsmetl	31,016	2,113,480	213,755	14,565,745	25,685	1,750,237
Wdmetl	1,235	9,753	9,330	73,684	351	2,774
Nelcmc	17	364	244	5,232	18	376
Elcmc	382	545	7,812	11,131	415	591
Trnseq	20	149	175	1,302	21	159
Othmn	3	34,463	36	453,135	2	28,322
Total	307,088	2,849,513	2,493,391	21,194,116	413,510	2,437,594

Sectors are: petroleum; food processing; beverages; tobacco; textiles; clothing; leather; paper; chemicals; rubber; non-metalic mineral products; base metals; wood and metal products; non-electrical machinery; electrical machinery; transportation equipment; and other manufactures.
Pollutants are: BOD- biological oxygen demand; and TSS- total suspended solids.